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THE ANTHROPOGENIC EFFECTS IN THE TEMPORAL AFFECTION OF THE STRUCTURAL COMPLEXITY OF THE ABRASION VERMETIDS PLATFORMS.

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- Resumen previo (Introducción + Conclusiones)

La diversidad de un ecosistema puede definirse como la variabilidad genética, específica, funcional y de hábitats de un sistema, y tiene dos características principales a ser consideradas: la riqueza, expresada en el número de tipos de elementos en el sistema, y la abundancia relativa de cada tipo (Odum 1953). Se considera la diversidad como un indicador del estado ecológico de los sistemas, siendo normalmente mayor en ecosistemas estables y menor en los cambiantes. Como Tilman (1994) expresó en su estudio de la diversidad en praderas; la estabilidad potenció la diversificación de nichos y por tanto, la diversificación de especies. Pero por otro lado, algunos estudios han demostrado que el pico de diversidad se encuentran en ecosistemas con un nivel intermedio de perturbación (ya sea hablando de frecuencia, intensidad o ambas), ya que si un ecosistema se mantiene sin perturbar el suficiente tiempo, éste empezará a perder diversidad por exclusión competitiva (Hardin, 1960; Huston, 1979; Begon et al., 1986). Hay diversidad de ejemplos para esta premisa; Connell (1978) propuso que los arrecifes de coral y las selvas tropicales mantenían su ampliamente diversidad estando sujetos a perturbaciones lo suficientemente frecuentes como para mantener un estado de "no-equilibrio". Él explicó que si el intervalo entre perturbaciones se agrandaba demasiado, el ecosistema tendería al equilibrio y pasaría a una comunidad con baja diversidad. Otro ejemplo de esta premisa son los campos intermareales de cantos rodados, en los que los cantos de tamaño mediano, sujetos a un nivel intermedio de perturbación debido a la rotación por la fuerza de las olas, resultan ser más diversos que aquellas piedras tan pequeñas que estarían siempre en movimiento y también más que aquellos cantos demasiado grandes como para ser movidos por las olas, rocas donde se establecería una especie dominante por ser la más competitiva (Sousa, 1979).

Ambas explicaciones clásicas que relacionan diversidad con estabilidad son correctas, pero el punto radica en entender si la diversidad que se está siendo medida, proviene de la diversificación de nichos o si proviene de niveles intermedios de perturbación.

La diversidad y la composición específica de la comunidad también se han relacionado con la productividad; definida como el cociente entre la producción y su biomasa (también conocida como tasa de renovación o "turnover") a esto se refiere, el tiempo necesitado por la comunidad para reemplazar su biomasa basal (Margalef, 1989)

Algunos estudios han mostrado que la diversidad tiene una correlación inversa con la productividad en comunidades macroalgales del infralittoral (Witman et al., 2008), donde se explicó que esta dependencia inversa estaba unida a la escala, siendo una interacción más fuerte a escalas menores. En otro ejemplo, Niell (1977) comparó la productividad de dos comunidades algales localizados en el Nord-este de España, con diferentes niveles de diversidad; encontró que las comunidades de baja diversidad soportaban grandes niveles de producción con poca biomasa; en contraste, los sistemas más diversos exhibían menores niveles de productividad en comparación con los de biomasa. Además, la composición de la comunidad puede estar también influenciada por los niveles de productividad; en algunas áreas litorales con elevada productividad, tales como emisarios o bocanas de puertos, las comunidades algales normalmente responden a grupos funcionales específicos como *Ulva* spp. o *Derbesia* sp. (Borowitzka, 1972; Rodriguez-Prieto et al., 2013)

Pero los valores de diversidad están también influenciados por la escala de estudio (ya sea espacial o temporal). Por tanto, los conceptos propuestos por Whittaker (1960): alfa, beta y gama diversidades son importantes para poder capturar un mayor espectro de puntos de vista sobre la diversidad de un ecosistema; siempre dependiendo del objetivo del estudio.

La α-diversidad tiene en cuenta la diversidad intrínseca de cada muestra por sí misma, cuantificando la riqueza especifica media. El índice de diversidad de Shannon-Weaver es uno de los índices más utilizados en ecología (Margalef, 1991; Odum, 1953), debido a su simplicidad de cálculo; mide la probabilidad de encontrar una especie dada en una comunidad concreta utilizando los datos de la proporción de cada especie (Shannon-Weaver, 1957). Por otro lado, Pielow propuso su índice de equitatividad (Pielow et al., 1966), el cual mide las similitudes entre muestras centrándose en la proporción de cada especie en cada muestra.

La β-diversidad ha tenido muchas aproximaciones desde que Whittaker (1972) la describiese originalmente como la "tasa de reemplazamiento de especies, o el cambio biótico a lo largo de gradientes ambientales" ; otros autores la han definido como las diferencias en cuanto a composición específica entre muestras para un área dada, con una escala espacial específica (Anderson, 2006).

A esta escala, la β-diversidad puede medirse tanto cuantitativamente como cualitativamente. De acuerdo con la medida original de Whittaker [$\beta = (\gamma/\alpha) - 1$]

(Whittaker, 1960; 1972), la beta diversidad respondería a la proporción en la que un área es mas rica que la media de muestras medidas. Alternativamente, Anderson (2006) propuso medir las disimilitudes entre las distancias de las muestras al centroide ideal del grupo, dando este parámetro una buena interpretación de beta. Para cumplir este objetivo, los modelos de similitud/disimilitud que podían usarse eran los propuestos por Jaccard, Bray-Curtiss o Sørensen. Así pues, ya que la β-diversidad puede medirse de diferentes formas (Koleff et al. 2003; Magurran, 2004), en este trabajo se utilizará esta última aproximación debido a la simplicidad de su cálculo. Es importante apuntar que los trabajos de Whittaker (1960, 1972 y 1977) han establecido la importancia de identificar las diversidades alfa y beta como los componentes de la diversidad general del ecosistema.

Todos estos parámetros pueden estudiarse fácilmente en un paisaje marino muy accesible y poco estudiado, formado por la interacción de factores biológicos, geológicos y climatológicos; hablamos de las plataformas calcáreas de abrasión. Estas plataformas son resultado de la interacción de varios factores. Primero, las propiedades calcáreas de la roca base, fácilmente erosionada por el hidrodinamismo; segundo, la estrecha amplitud mareal que permite que se forme la plataforma; y tercero, las comunidades que se desarrollan en la plataforma reduciendo y ralentizando los procesos erosivos una vez ésta se ha formado.

Las plataformas de abrasión se ubican en el infralittoral más somero (Pérès and Piccard, 1964) con un máximo de profundidad que habitualmente no supera los 30 cm. Estos paisajes permiten la formación de un gran número de microhabitats y ricas comunidades de flora y fauna, convirtiéndose en puntos de elevada diversidad (Chemello, 2009; Milazo et al., 2016). La plataforma, en condiciones no perturbadas, se encuentra colonizada por algas tales como *Padina pavonica* (Linnaeus), *Palisada tenerrima* (Cremades) o especies del género *Cystoseira* (Chemello, 2009; Millazo et al., 2016; Terradas, 2018).

En estos paisajes, el hidrodinamismo es más fuerte en la zona de rompiente, y la profundidad de la plataforma normalmente es menor cuanto más cerca del margen interno de la misma; esto provoca que cuando se dan eventos de bajamar, se cree un gradiente de estrés debido a la disponibilidad hídrica desde la cresta hasta la zona proximal de la plataforma. Localizándose el mayor estrés en el margen interno y creándose un área de perturbación intermedia en la zona más externa de la plataforma.

Aquí en el Mediterráneo, las plataformas de abrasión son especialmente interesantes debido a la presencia de una estructura biogénica formada a partir de la interacción entre un alga roja corallinacea y un molusco filtrador sésil; se trata en este caso de los arrecifes de vermétidos. (Terradas, 2018). Estas estructuras similares a arrecifes están consideradas como grandes bioindicadores de aguas limpias (Rodriguez-Prieto et al., 2013), y sirven como protección para la línea de costa y la plataforma frente a la fuerza erosiva de las olas

En este estudio, el objetivo es medir la diversidad (α y β) entre tres puntos de la costa de Alicante, con distintos grados de presión antrópica debido a la presencia del emisario del Rincón de León y el puerto de Alicante. Los objetivos número dos y tres, pasan por dilucidar si la distancia de la comunidad al punto más expuesto de la plataforma influye en la diversidad y si existe algún patrón temporal.

Por tanto, las hipótesis propuestas son que la diversidad será menor más cerca del emisario, ya que la productividad será mayor; y que a su vez los ambientes más diversos se encontrarán más cerca de la zona de rompiente de la plataforma, respondiendo a la hipótesis de la perturbación intermedia

Las conclusiones obtenidas del estudio nos llevan a determinar que la existencia de un arrecife de vermétidos bien desarrollado (Cabo de las Huertas) fomenta la diversidad (α y β) y genera comunidades típicas de zonas limpias o poco antropizadas.; por tanto la presencia del emisario, el cual fue una potencial causa de la desaparición de los vermétidos en Agua Amarga, puede relacionarse con la degradación de la comunidad de esta localización. Por otro lado, la β-diversidad pareció no estar conectada a la localidad sino a la cantidad de sedimento en el ambiente (Santa Pola). Así que el impacto que pueda tener el sedimento podría ser una de las causas para la mayor afección de la beta diversidad de la comunidad.

Finalmente, recomendamos una investigación más exhaustiva para poder comprobar si existe una relación entre la estacionalidad y las diferentes diversidades, ya que los tres meses durante los que se realizaron los muestreos no parecieron presentar significatividad en los test pese al conocido dinamismo de las comunidades del infralitoral superior

- Resumen

La diversidad de un ecosistema tiene dos características principales a tener en consideración: la riqueza específica y la abundancia relativa de cada especie. Según Whitaker existen 3 escalas de diversidad: alfa, beta y gamma; siendo la alfa-diversidad una medición de la diversidad intrínseca de las muestras, la beta una medida de la variación entre muestras. Estos parámetros pueden dar información del estado ecológico del ecosistema, y por tanto, puede ser muy interesante cuantificarlos desde el punto de vista de la gestión. En este trabajo se ha estudiado como cambia la diversidad en un paisaje típico del Mediterráneo cálido muy accesible para su estudio, las plataformas de abrasión. Durante el estudio, el foco se centró en 3 localidades con plataformas de abrasión de la costa alicantina con diferentes niveles de presión antrópica debida al emisario del Rincón de León, ya que las aguas salientes de este canal portan nutrientes que pueden enriquecer el medio; El Cabo de las Huertas, La playa de Agua Amarga y el Cabo de Santa Pola. En cada localidad se diferenciaron 3 horizontes (según la distancia a la zona de rompiente) para evaluar el patrón de la composición especifica en base a las diversidades (α y β) entre localidades y zonas litorales. Los resultados han mostrado una clara diferencia entre la zona más externa de la plataforma y las áreas interiores, a la vez que la localidad de Santa Pola presentaba un menor grado de diversidad probablemente debido a la elevada abundancia de sedimento. Por otro lado, las comunidades fitobentónicas de la playa de Agua Amarga, la más cercana al emisario, se presentaron compuestas por especies típicamente oportunistas o con un gran rango de tolerancia al estrés.

Palabras clave

Plataformas de abrasión; α-diversidad; β-diversidad; Presión antrópica.

- Summary

The diversity of an ecosystem has two main characteristics to be considered: The specific richness and the relative abundance of each species. According to Whitaker, diversity can be considered within 3 scales: alpha, beta and gamma; defined the α-diversity the diversity of each "sample" by itself and β-diversity as a measure of the variation between samples. These parameters can give information of the ecological status of an ecosystem, and so, may be very interesting to quantify from the point of view of management. In this study, we have studied the diversity changes in a typical warm Mediterranean seascape, easily accessible for its study, the abrasion platforms. During this work, we focused in 3 locations with abrasion platforms through the coast of Alicante with different levels of anthropogenic pressure caused by the sewage outfall of Rincon de Leon, as the outflowing water carry a huge nutrient load that might enrich the environment; The Cabo de las Huertas, The beach of Agua Amarga and the Cabo de Santa Pola. At each location we differentiated 3 littoral zones (according to the distance to the outer margin of the platform) in order to evaluate the pattern of specific composition regarding the diversities (α and β) between locations and littoral zones. The results showed clear differences between the outer margin and the inner zones of the platform, at the same time as Santa Pola performed a lesser grade of diversity probably caused by the high sediment load. On the other hand, the algae communities of Agua Amarga, the closer location to the sewage outfall, were composed mainly by opportunistic and stress-tolerant species.

Keywords

Abrasion platforms; α-diversity; β-diversity; anthropogenic pressure.

Index

1. Introduction

The diversity of an ecosystem can be defined as the genetic, specific, functional and biotopical variability of a system, and has two main characteristics to be considered: the richness, expressed in the number of types of elements in the system, and the relative abundance of each type (Odum 1953). Diversity is commonly considered as an indicator of the ecological status of a system, usually being greater in stable ecosystems and smaller in the changing ones. As Tilman (1994) stated in his study of diversity in grasslands, the stability promoted the diversification of niches and thus, the diversification of species. But on the other hand, some studies have shown that the peak of diversity is placed in ecosystems with an intermediate level of disturbance (either talking of frequency, intensity or both), as if an ecosystem stays undisturbed for a long enough period of time, it will begin to lose diversity, due to competitive exclusion (Hardin, 1960; Huston, 1979; Begon *et al.*, 1986). There are some examples to this premise; Connell (1978) proposed that tropical reefs and rainforest maintain its widely known diversity by being subjected to disturbances often enough in order to maintain a state of “non-equilibrium”. He explained that if the interval between disturbances lengthened too much, the ecosystem would tend to equilibrium and to a low-diversity community. Another example of this premise are the intertidal boulder fields, in where the medium-sized boulders, which are subjected to an intermediate level of disturbance due to being turned around because of the waves, turn out to be more diverse than those small enough to be constantly disturbed by the force of the waves or those which are seldom disturbed because of its great size, allowing the dominance in cover by the most competitive species (Sousa, 1979).

Both classical explanations about the relation between diversity and stability are correct, but the point relays into understand if the diversity that is being measured comes from niche diversification or from intermediate disturbance levels.

Diversity and community composition have also been related to productivity; defined as the ratio between the production and its biomass (also known as renovation rate or “turnover”) that is, the time needed by the community to replace its base biomass (Margalef, 1989). Some studies have stated that diversity has an “inverse” or “hump-shaped” correlation with productivity in subtidal macroalgae communities (Witman *et al.*, 2008), where was stated that this inverse dependence was scale-linked, being stronger in small local scales; in another example, Niell (1977) compared the productivity of two algal communities located in north-western Spain with different levels of diversity; he found that in low diversity communities, high productivity is supported by a low biomass; in contrast, more diverse systems exhibit low productivity values relative to those of biomass. Also, the community composition can be influenced by the productivity levels; in some littoral areas with high productivity, such as sewage outfalls or harbours, the algal communities growing generally respond to specific functional groups, being commonly found in these environments filamentous and laminar green algae such as *Ulva* spp or *Derbesia* sp (Borowitzka, 1972; Rodriguez-Prieto *et al.*, 2013) (Fig. 1).

Figure 1. Community composed mainly by *Ulva* sp at the beach of Agua Amarga, at 3,5 km from the outfall. (Alcaraz L.)

But diversity values are also highly influenced by the scale of study (whether spatial or temporal). Thus, the concepts proposed by Whittaker (1960): alpha, beta and gamma diversity are important in order to capture a major spectrum of points of view of the diversity of an ecosystem, depending on the objective of the study.

α-diversity takes into account the diversity of each “sample” by itself, quantifying the mean species richness. The Shannon–Weaver’ diversity index (Shannon index for the rest of the study) is one of the most used index in ecology to measure the (alpha) diversity of a community (Margalef, 1991; Odum, 1953), and one of the most easily calculable; it measures the probability to find a species in a given community by using the data of the proportion of each species (Shannon-Weaver, 1957). On the other hand, Pielou proposed his index of evenness (Pielow *et al.,* 1966), which measures the similitudes between samples, focusing on the proportion of each species present at each sample.

β-diversity has had many approaches through years; Whittaker (1972) originally described it as " the extent of species replacement or biotic change along environmental gradients", but other authors have defined it as the differences in species composition between samples for a given area with a specific spatial scale (Anderson, 2006).

At this scale, β-diversity can be measured either quantitatively or qualitatively. According to Whittaker's original measure [$\beta = (\gamma/\alpha) - 1$] (Whittaker, 1960; 1972), the beta diversity would respond to the proportion by which a given area is richer than the average of samples within it. Alternatively, Anderson (2006) proposed that measuring the dissimilarities between the distances of the samples to the centroid's group, would give a good interpretation of beta. In order to accomplish this objective the similarity/dissimilarity models, that could be used would be the proposed by Jaccard, Bray-Curtiss or Sørensen. Then, as β-diversity can be measured in many different ways (Koleff *et al.* 2003; Magurran, 2004), we will be using this last approach, due to its calculation simplicity, in order to study this parameter. It's important to point out that the works of Whittaker (1960, 1972 and 1977) have established the significance of identifying α and β-diversity as components of the overall diversity.

All this parameters can be easily studied in a very accessible seascape, generated from the interaction of some biological, geological and climatological processes; we are talking about the limestone abrasion platforms. These platforms are the result of the interaction of some factors. First, the properties of the limestone base rock, easily eroded by the hydrodynamism; second, the low tidal wideness that allows the platform to be formed; and third, the communities that develop on the platform dampening the erosive processes.

The abrasion platforms are placed in the shallowest infralittoral (Pérès and Piccard, 1964) with a maximum depth usually not surpassing the 30cm. These seascapes allow a great number of microhabitats and rich communities of flora and fauna to develop, becoming hotspots of biodiversity (Chemello, 2009; Milazo *et al.*, 2016); but even though these environments are easily accessible, they are not greatly studied. The platform, in undisturbed conditions, is colonised mostly by red and brown algae such as *Padina pavonica* (Linnaeus) (Fig. 2), *Palisada tenerrima* (Cremades) (Fig. 2) or species of the genus *Cystoseira* (Fig. 3) (Chemello, 2009; Millazo *et al.*, 2016; Terradas, 2018).

Figure 2. Photo of a specimen of *Padina pavonica.* (Alcaraz L.)

Figure 3. Photo of a specimen of *Cystoseira stricta* (Montagne in Durieu) and *P. tenerrima*. (Alcaraz L.)

In these seascapes, the hydrodynamism is stronger at the ridge, and the depth of the platform usually grows shorter the closer to the inner margin; this provokes that when low sea level events take place, a gradient of stress by water availability is formed from the ridge to the proximal zone, being the highest stress located at the inner margin and creating an area of intermediate disturbance at the outer margin (Fig. 4).

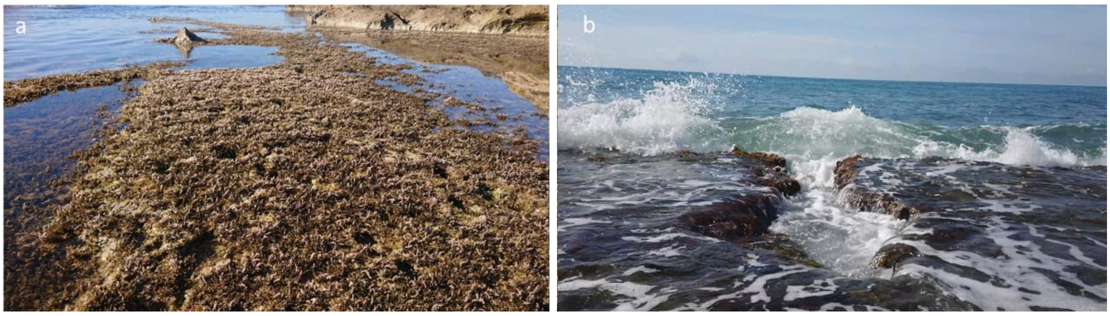

Figure 4. Low–sea–level event laying down high levels of mortality at Cabo de las Huertas (Image of the proximal zone) (a) and high hydrodynamism at Cabo de las Huertas (b) (Alcaraz L.).

Here in the Mediterranean, the abrasion platforms are also interesting because of the presence of a biogenic structure formed by an interaction between a red coralline alga and a sessile filtering mollusc; these structures are the vermetids build-ups (Fig. 5), (Terradas, 2018). These reef-like shallow structures are considered a great bioindicator of pristine waters (Rodriguez-Prieto *et al.,* 2013) and serve as a protection for the coastline and the platform against the erosive forces of the waves.

Figure 5. Photo of a colony of Dendropoma *lebeche (*Templado J.) with *Neogoniolithon brassica-florida* (Harvey) at Cabo de las Huertas (Alcaraz L.)

In this study we aim to measure the diversity (α and β) between three points of the coast of Alicante which differed in their anthropogenic pressure due to the sewage pipe of "Rincon de Leon" and Alicante harbor. The second and third objectives are to discern if there is any effect in the diversity coming from the distance of the community to the outer margin of the platform, and if this differences have a temporal pattern.

Therefore, the proposed hypothesis are that the diversity will be lower the more closer to the outfall, as the productivity will be greater, and that it will also increase as more close to the outer margin, responding to the intermediate disturbance theory.

2. Materials and methodology

2.1 Study site

The treatment plant of “Rincon de Leon” was built during the eighties at the city of Alicante, Spain; this treatment plant pours its wastewaters to the Mediterranean through a sewage pipe, discharging a volume close to 12 Hm^3 of water; the sewage flowing through the pipe contains an annual mean value close to 727 T of nitrates, 86 T of phosphate and 1.013 T of COD (Data in appendix 5). These compounds are a threat to the abrasion platforms, because of the potential eutrophication of the environment where these structures are placed (Ramos-Esplá *et al.*, 2008; Chemello, 2009; Milazo *et al.*, 2016).

Three sites were studied with different levels of anthropogenic influence; one of the locations was the Playa de Agua Amarga (AA) Fig. 6-b, located approximately 3,5 km far from the outfall pipe with great anthropic influence; the second location of study was the abrasion platforms of the Cabo de Santa Pola (CSP) Fig. 6-c. with lower anthropic influence; the las point, was an area of the Cabo de las Huertas (CH) Fig. 6-a, a rocky shore with well-developed abrasion vermetid platforms. At each location there were selected 3 sites separated at least 20m and in each site we sampled at 3 distances from the breaking point of the waves (littoral zones Proximal, Distal and Ridge (Fig 8)). The sampling was performed during three months; December, February and March. January was left out of the sampling due the fact that the weather did not allowed us to perform the inventories. For each location, month, site and littoral zone, we replicated three times (n=3).

a b c

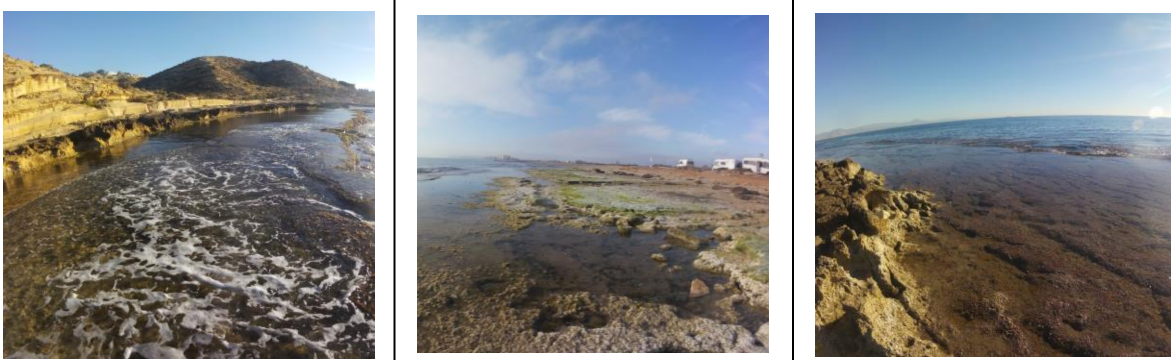

Figure 6. Photo of the platform at Cabo de las Huertas (a); Agua Amarga (b) and Cabo de Santa Pola (c) (Alcaraz L.)

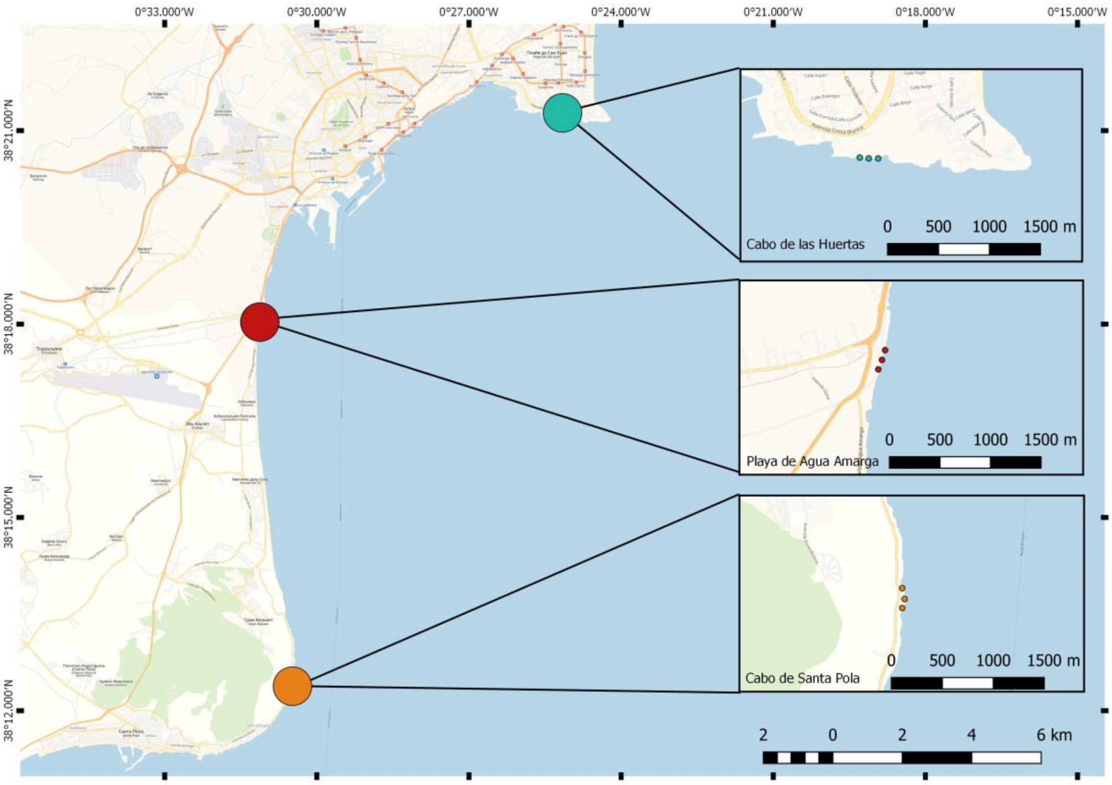

Figure 7. Map of the locations of the experiment (Elaborated with QGis) (Alcaraz L).

Figure 8. Relative placement of the 3 Littoral zones. Photo of the platform at the Cabo de las Huertas (Alcaraz L.).

2.2 Sampling

The sampling method consists in a measurement of the percentage of the area occupied by each species (Sant, 2003). This is done with a 25x25cm square divided in 25 squares of 5x5cm each (Fig. 9). For each algae and each 5x5cm square, it is given a value from 1 to 4 regarding of the percentage the alga occupies in that square; then the values of each square are added to a total percentage (a value of 4 for all 25 squares would mean a 100% of coverage). As this was not a floristic study, we did not took the samples of the squares to the lab, so this was a non-destructive method. For this same reason, there were algae species left out of the analysis but, as it would mean a very small percentage of the coverages, it would not distort the results significantly. (Sant,. 2003). In addition to the algae coverages, other explanatory variables were measured, in order to obtain auxiliary information; the variables measured were the relative abundance of sediment and bare space, the water height, and the length of the talus of the canopy former algae in each square; The mean water temperature was also measured three times (as replicas) at each littoral zone at 09:00 AM, 11:00 AM and 01:00 PM. When possible, the height of the vermetid rim was measured, as "bioconstruction height". The last explicative variable taken into account was the photoperiod duration.

Figure 9. Photo of the 25x25cm metal square utilized in the samplings (Alcaraz L).

The algae that could not be identified "in situ" were collected in bags and brought to the lab for later identification with the guides elaborated by Alfonso and Sansón (2009), Cormaci *et al.* (2012 and 2014) and Giaccone *et al.* (2003) (Appendix 6).

2.3 Data analysis

Principal coordinate analysis (PCoA) (PRIMER v.6, Clarke and Gorley, 2006) was used as the ordination method for exploring the trends in the differences between the algae assemblages composition. The dissimilarity matrix, which was calculated using the Bray–Curtis index, was used to construct PCoA plots. In the same line, there were elaborated bubble plots in order to explore the abundance of some characteristic algae at each location.

Data of Shannon diversity (H' with $\log_e$), Pielow's evenness (J') were obtained using the software Primer v.6 (Clarke and Gorley, 2006) from the raw data. Then, this variables were analysed by using a four-way ANOVA with "Location" (three levels), "Littoral zone" (three levels), "Month" (three levels) and "Site" (three levels) as factors.

Location, littoral zone and month were treated as fixed and orthogonal, while site was random and nested in littoral zone. Cochran's test was used to check for the homogeneity of variances (Winer, 1971). Neither of the three ANOVAs presented homogeneity of variances even with transformation, so as there were more than 30 samples and the statistical model was balanced, the ANOVAs were considered robust enough to carry on with the analysis. The significance level was, however, set at the 0.01 level to reduce a type I error (Underwood, 1997). When appropriate, Student–Newman–Keuls' (SNK) test was employed to separate means (at p = 0.05); this three univariate analysis were carried out with the R-project software (R Core Team, 2019). The packages used in the analysis were the "GAD" package (Sandrini-Neto and Camargo, 2019) in order to correct the mean square estimators, and the "sciplot" package (Morales *et al.*, 2017) in order to create the graphics.

A permutational multivariate ANOVA (PERMANOVA+ software, Anderson, 2001) based on the same design used for the univariate analyses was carried out to test for differences in the algal species composition of the platform assemblages. Following the permutational test, a pairwise test was carried out to test differences among groups. Also, SIMPER analysis were carried out in order to identify the species that contributed the most to differences between samples for each factor (Clarke and Gorley, 2006).

β-diversity was studied by first transforming the data following the Jaccard presence/absence index and constructing a similarity matrix (Anderson *et al.* 2011); then, permutational analysis of multivariate dispersions (PERMDISP) (Clarke and Gorley, 2006) was performed in order to compare the specific variability of the samples between different locations and littoral zones; this was made by measuring the mean distances of the samples to the centroid; as this value is interpretable as a proxy to β-diversity (Anderson *et al.* 2006).

2.4 Chronogram

Months	December				January				February				March				April				May			
Weeks	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Sampling planning.																								
Sampling and algae identification.																								
Data treatment																								
Data analysis																								
Bibliography research.																								
TFG elaboration																								

Table 1. Chronogram of the study planning.

According to Table 1, the samplings were performed during the first three weeks of each month (except January) and at the end of each month the data were copied in a Microsoft Exel sheet in order to further analysis.

3. Results

3.1 Principal coordinates analysis (PCO) of the algal communities.

Results of the PCO analysis (Fig. 10) showed the samples distributed along the plane defined by the two first PCOs. PCOs I and II account for 60.3% of the total variance of the data set (37.5% and 22.8%, for PCOs I and II, respectively).

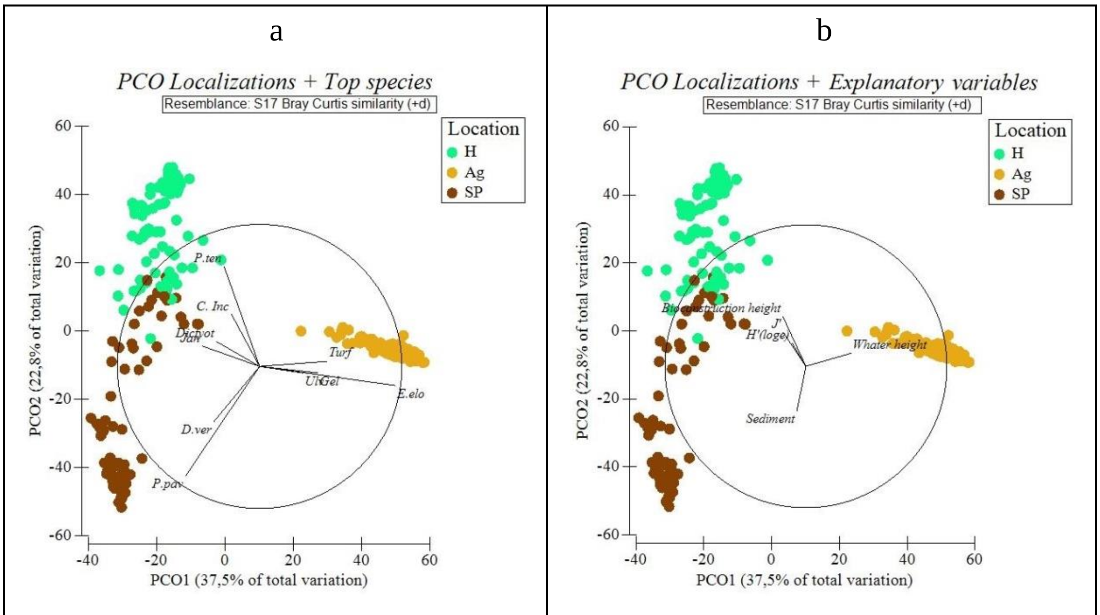

Figure 10. PCOs showing the samples separated by locations (green – CH; brown – CSP; yellow – AA). The vectors show the top species present at each location (a) and the explanatory variables measured (b). Elaborated with Primer v6.

At the first PCOaxis, the differences between the group of CH+CSP and AA becomes evident; while in the second PCO axis, the differences between CH and CSP are less clear. The vectors in Fig. 10-a represent that the algae of the genus *Ulva*, *Gelidium*, Turf and *Ellisolandia elongata* (Ellis and Solander) have a greater presence at AA; it is also shown that *Dasycladus vermicularis* (Scopil) and *Padina pavonica* appear more frequently at CSP; and that the species of the genus *Jania*, *Dictyota*, the encrusting corallinaceous algae, and *Palisada tenerrima*, are characteristic of CH.

Otherwise, the vectors represented in Fig. 10-b, show that the water height is greater in AA; that there is a trend of a greater diversity and evenness at CH along with a greater bioconstruction height at CH. It is important to notice that the amount of sediment in Cabo de Santa Pola outperformed the other two locations (Fig. 11).

Figure 11. Sampling square in the distal zone of Santa Pola with high abundance of sediment and dominance from *P. pavonica.*

The PCoA of each location separately (data available in appendices 1.1, 1.2 and 1.3) showed the trends of the differences between littoral zones. In Cabo Huertas, the proximal zone tended to be more different than distal and ridge, being this last one the most diverse littoral zone, with higher values of H' and J'; *Palisada tenerrima* was the dominant alga at the proximal littoral zone, along with a greater level of sediment; *Dictyota*, *Dasycladus vermicularis*, *Ceramium sp* and *Cladophora sp*, dominated in the distal zone, where the water was higher; and *Jania sp*, *Hypnea musciformis* (Wulfen), Turf and the encrusting corallinaceous algae (Cor. Inc) were the most abundant at the ridge. At Agua Amarga there was no clear differentiation between littoral zone, being the Ridge slightly differentiated and more diverse; Cabo de Santa Pola presented two main groups: the Distal + Proximal, inhabited mostly by *Padina pavonica* owning the highest level of sediment on the location, and the Ridge, with the rest of the top algae and with the higher diversity and evenness.

3.2 PERMANOVA and Simper of the algal composition per location

The PERMANOVA showed that the species composition of the algal communities was affected by two second-order interactions (p.value<0.05) (Table 2): Firstly, the one regarding to the interaction between the location and the littoral zone; secondly, the interaction of location and month.

Source of variation	df	MS	Pseudo-F	P
Location (=Loc)	2	$2,03 \times 10^5$	133,31	0,001
Littoral zone (=Lit.Z)	2	28148	22,341	0,001
Month (=Mo)	2	19712	16,434	0,001
Site (Loc)	6	1524,4	2,9072	0,001
Loc X **Lit.Z**	4	17362	13,781	0,001
Loc X **Mo**	4	7340,2	6,1198	0,001
Lit.Z X **Mo**	4	1655,5	1,4526	0,11
Li X **Site (Lo)**	12	1259,9	2,4029	0,001
Mo X **Site (Lo)**	12	1199,4	2,2875	0,001
Loc X **Lit.Z x Mo**	8	1578,8	1,3853	0,081
Li X **Mo** X **Site (Lo)**	24	1139,7	2,1736	0,001
Residuals	162	524,34		
Total	242			

Table 2. 4-factor PERMANOVA on the specific composition of de communities depending on the location, the littoral zone, the month and the site ($\alpha = 0.05$).

The pair-wise tests (data in appendices 2.1.1 and 2.1.2) of both interactions showed that all locations had differences regarding to the community composition (p. value<0.05). At CH, there were no significative differences through months, while the proximal horizon was different to the other littoral zones; in AA, only December showed significative differences among the other months, while the littoral zones of distal and ridge were different between them; regarding to SP, significance was only found between December and February, and also among the distal zone and the ridge.

Simper analysis (appendices 2.2.1, 2.2.2 and 2.2.3) along with bubble graphs for the most abundant algae, showed that *P. tenerrima* in the proximal zone (90.15% of contribution to similitude), *Dictyota* spp at the distal horizon (46.4% of contribution) and *Jania* sp. at the ridge (47.55% of contribution) were the dominant algae in Cabo de las Huertas; being *P. tenerrima* the alga that contributed the most to the differences between zones (Fig. 12).

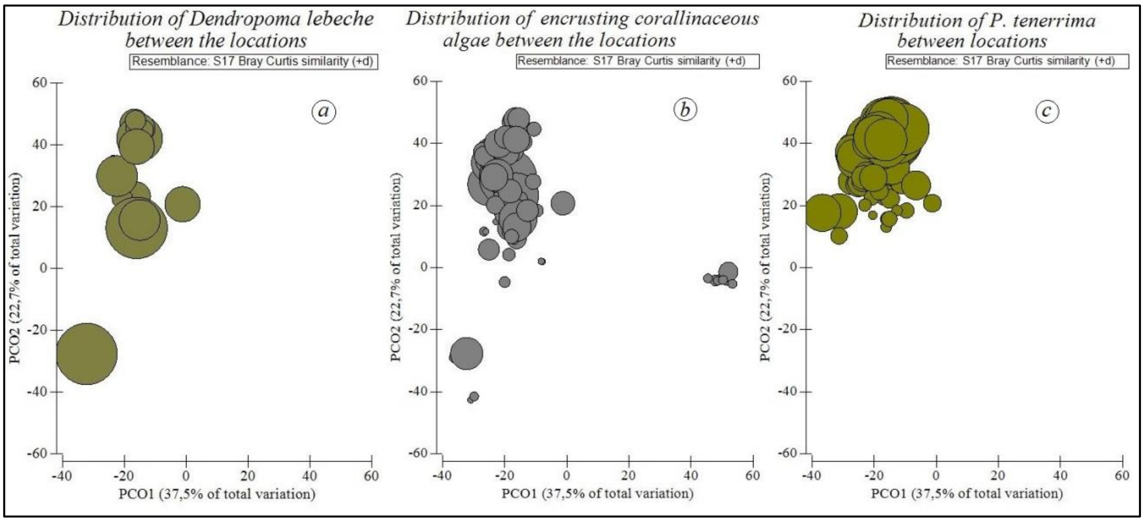

Figure 12. Distribution of *D. lebeche* (a), encrusting corallinaceous algae (b) and *P.tenerrima* (c) between locations accordingly to Fig. 10.

In Agua Amarga, the dominant alga was *E. elongata*, with a contribution to the similitude of the samples of 94.17%, 66.76% and 70.64% in the proximal, distal and ridge zones respectively (Fig 13); also, *E. elongata* along with Turf, contributed to the differentiation of the three horizons.

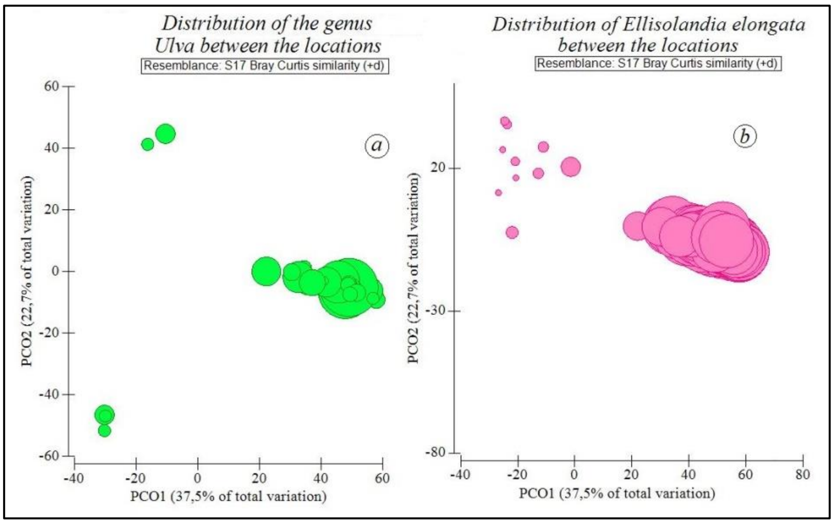

Figure 13. Distribution of *Ulva* sp (a) and *E. elongata* (b) between locations accordingly to Fig. 10.

Otherwise, *P.pavonica* was the most abundant species in the proximal and distal zones in Cabo de Santa Pola (73.41% and 71.34% of contribution respectively), being *Jania sp.* (Lamouroux) the dominant alga at the ridge (43.67% of contribution); *P.pavonica* (Linnaeus) also contributed the most to the differences between littoral zones (Fig. 14).

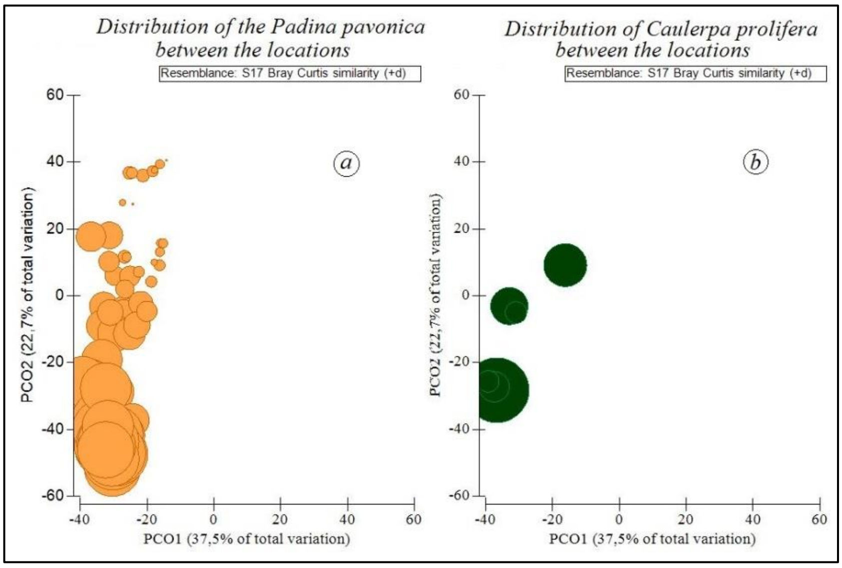

Figure 14. Distribution of *P. pavonica* (a) and *C. prolifera* (b) between locations accordingly to Fig. 10

3.3 Analysis of α-diversity.

3.3.1 Shannon diversity.

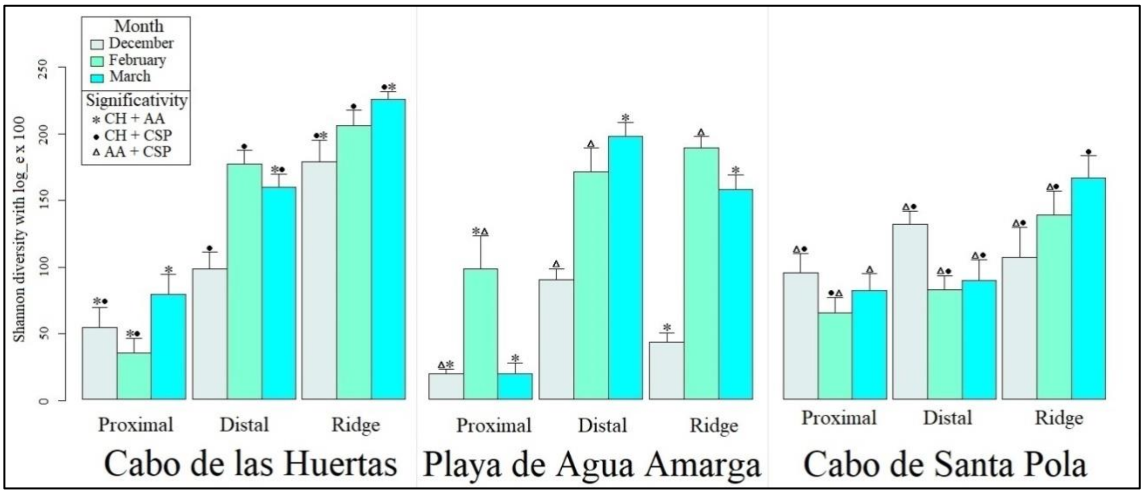

Figure 15. Bar-plot of the trends in the Shannon diversity index, calculated with the logarithm of base *e*, comparing the 3 locations between the littoral zones and the months. The asterisks indicate significative differences between CH and AA; The bold circles point significative differences between CH and CS; and the triangles show significative differences between CSP and AA. Elaborated with R-project.

The ANOVA indicated a significative interaction between the three fixed factors ($p.value<0.05$) (Table 3) and thus, a SNK test was performed to see the potential differences between the factors. The test showed that, in December, CSP presented a higher value of H' than the other two locations in the proximal and distal littoral zones, while at the ridge, the highest Shannon diversity index was measured in CH; during February, CH had higher values of H' in the three littoral zones, except for the proximal zone, where the higher value stood at AA; in March, CH presented higher levels of H' at the ridge and had no significative differences with CSP at the proximal zone, being AA the most diverse location at the distal zone.

Diversity was lower the first months at both three locations, with the exception of Santa Pola, where December presented higher values of H' at the distal zone and lower values at the ridge. Within each location, the diversity was higher at the distal and ridge zones especially at CH. (Tables and graphs for the SNK tests are found at appendices 3.1.1 and 3.1.2.)

Source of variation	df	MS	F	P
Location (=Loc)	2	19431,6	6,0	0,037
Littoral.zone (=Lit.Z)	2	201754,1	51,6	$1,3x10^{-06}$
Month (=Mo)	2	41497,8	20,7	0,0001
Lit.Z X Mo	4	26971,8	6,9	0,0040
Loc X Lit.Z	4	24822,1	12,4	$3,2x10^{-04}$
Loc X Mo	4	9596,2	6,8	$4,3x10^{-05}$
Site (Loc)	6	3255,0	2,3	0,0371
Loc X Lit.Z X Mo	8	7742,3	5,4	$3,5x10^{-06}$
Lit.Z X Site(Loc)	12	3913,5	2,8	0,0018
Mo X Site(Loc)	12	2005,4	1,4	0,1638
Residual	186	1421,2		

Table 3. 4-factor ANOVA on the Shannon diversity index (with naperian logarithm) variation depending on the location, the littoral zone, the month and the site ($\alpha = 0.01$).

3.3.2 *Pielow's evenness*

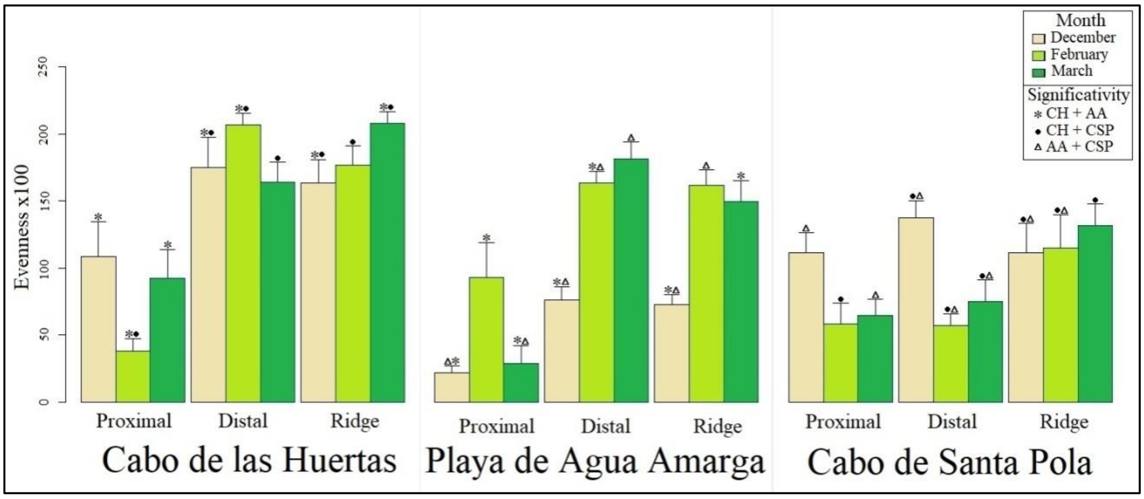

Figure 16. Bar-plot of the trends in the Pielow's evenness index, comparing the 3 locations between the littoral zones and the months. The asterisks indicate significative differences between CH and AA; The bold circles point significative differences between CH and CS; and the triangles show significative differences between CSP and AA. Elaborated with R-project.

In the case of the Pielow's evenness the performed ANOVA showed the same significative third-order interaction between the three fixed factors (p.value<0.05) (Table 4). According to the posterior SNK test: during the month of December, CH presented Higher values of J', having AA the lowest levels; in February, AA had the highest Pielow's index values at the proximal zone, while the distal zone and the ridge were more even at CH; during March, CH presented higher or equal levels of J' than the other locations (not having significative differences with CSP in the proximal zone and with AA in the distal one).

Pielow's evenness showed different patterns at each location regarding to the temporality: At CH, the proximal zone presented lower levels of J' in February while the distal showed its maximum, being the ridge higher in March; AA presented lower values of evenness in December in the three littoral zones; on the other side, during December, CSP had higher levels of Pielow's index in the proximal and distal zones, while the ridge had no variation through months. (Tables and graphs for the SNK tests are found at appendices 3.2.1 and 3.2.2).

Source of variation	df	MS	F	P
Location (=Loc)	2	62823,4	12,2	0,008
Littoral.zone (=Lit.Z)	2	140436,1	62,9	$4{,}35x10^{-07}$
Month (=Mo)	2	3824,9	0,9	0,431
Lit.Z X Mo	4	8358,3	4,1	0,003
Loc X Lit.Z	4	17618,1	7,9	0,002
Loc X Mo	4	30370,0	7,2	0,003
Site (Loc)	6	5128,7	2,5	0,023
Loc X Lit.Z X Mo	8	6990,5	3,4	0,001
Lit.Z X Site (Loc)	12	2232,1	1,1	0,363
Mo X Site (Loc)	12	4236,9	2,1	0,020
Residual	186	2030,3		

Table 4. 4-factor ANOVA on the Pielow's evenness index variation depending on the location, the littoral zone, the month and the site (α = 0.01).

3.4 β-diversity analysis

The results of the first PERMDISP (Table 5) (p.value<0.05) showed that CSP presented values that were closer to centroid than AA and CH (40.45 versus 47.07 and 47.44) (Table 6). The PERMDISPs applied to each location separately (appendixes 4.1, 4.2 and 4.3) showed the possible differences between the littoral zones: CH and AA did not showed differences between its littoral zones (P.values>0.05); CSP presented differences between the distal zone and the ridge and proximal, showing the distal zone a lower beta diversity value than the ridge (28.35 versus 35.35 and 35.55) (p.values<0.05).

Groups	t	P(perm)
(H, Ag)	0,31923	0,762
(H, SP)	4,3907	1,00E-03
(Ag, SP)	4,6009	1,00E-03

Table 5. T statistic and P.values of the distances to centroids between locations, using Jaccard's similarity (α = 0.05).

MEANS AND STANDARD ERRORS		
Group	**Mean**	**S.E**
H	47,449	0,96892
Ag	47,07	0,68496
SP	40,459	1,2631

Table 6. Means and standard errors from distances to centroids in each location, using Jaccard's similarity index of table 5.

4. Discussion

The differences between the communities in the beach of Agua Amarga and the ones in the zones of Santa Pola and Cabo de las Huertas are explainable due to its proximity to the sewage pipe and to the eutrophication derived from it. Also, the biocenosis growing at Agua Amarga (appendix 2.2.2), are distinctive of mild eutrophicated conditions (Ramos-Esplá *et al.*, 2008; Pinedo *et al.*, 2007; Ballesteros *et al.*, 2007) and are probably also differentiated by the hydrodynamic stress driven by the absence of a vermetid rim.

On the other hand, the disparities, regarding to H' and J', can be explained by the fact that CH presents a vermetid rim, which elevates the bottom of the platform at the ridge, creating a "midlittoral level" with a higher hydrodynamism (Terradas *et al.*, 2018) fostering the nutrient uptake rates, the water renovation and thus, the productivity (Rodriguez-Prieto *et al.*, 2013). At the same time, the disturbance frequency could be increased due to low-sea-level events when a vermetid rim is developed; notice that in the Mediterranean, this low-sea-level events can reach >40 cm (or even >80cm) in spring (Bernard *et al.*, 1983; Rodriguez-Prieto, 2013) (Fig. 4). This translates into an area with an intermediate level of disturbances, compared to the rest of the flatter and deeper platform, promoting local diversity (Connell, 1978; Sousa, 1979). Also, this vermetid rim allowed the formation of well differentiated horizons (Chemello, 2009; Millazo *et al.*, 2016; Terradas, 2018); possibly because of this reason and because of its distance from the outfall, CH presented species typical from undisturbed areas.

Differently, CSP presented lower levels of diversity and evenness than the other two locations; this could be clarified due to the greater sedimentary load found in this location (Fig 10), this environmental factor possibly fostered fewer species to develop, being the Dictyotaceae (mainly *P. pavonica*) the most abundant species at CSP, whose growth does not seem to be extremely affected by the presence of sediment (Terradas, 2018; Terradas *et. al.*, 2018). Also, the greater sediment pressure at CSP may be facilitated by the major length of the platform of this location.

Beta diversity was lower at Cabo de Santa Pola, while this parameter was higher at Cabo de las Huertas and Agua Amarga. This could be explained accordingly to the negative correlation between the β-diversity and the sediment amount; being this parameter smaller as the mass of sediment grows (Balata *et al.* 2008). This probably happened at CSP as this location has a greater amount of sediment.

Thus alpha and beta diversity differed in their responses to the variety of factors affecting the platforms; making it difficult, at the same time as interesting, to study this parameters looking forward to a greater understanding of this communities ecology

5. Final conclusions

We determine that the existence of a well-developed vermetid reef (Cabo de las Huertas) promotes diversity (α and β) and generates more pristine-like assemblages; thus the presence of the sewage outfall, which was a potential cause of the disappearance of the vermetids of Agua Amarga, can be related to the degradation of this location's community. On the other side, β-diversity appeared to be non-linked to location, only to the amount of sediment in the environment (Cabo de Santa Pola). So the sedimentary impact could be one of the causes of a greater affection in the β-diversity of the community.

Finally we recommend further investigation in this field in order to check if there is any relation between seasonality and the different diversities, as the amount of three month did no presented significance at the tests despite the known dynamism of the upper infralittoral assemblages.

6. Acknowledgements

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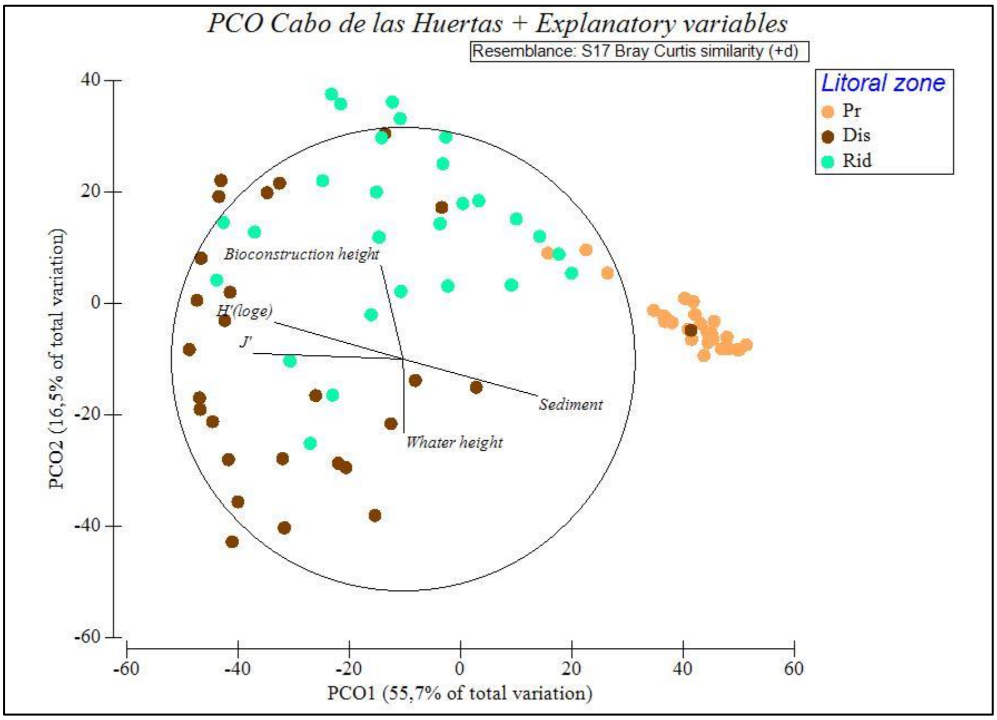
8. Appendices

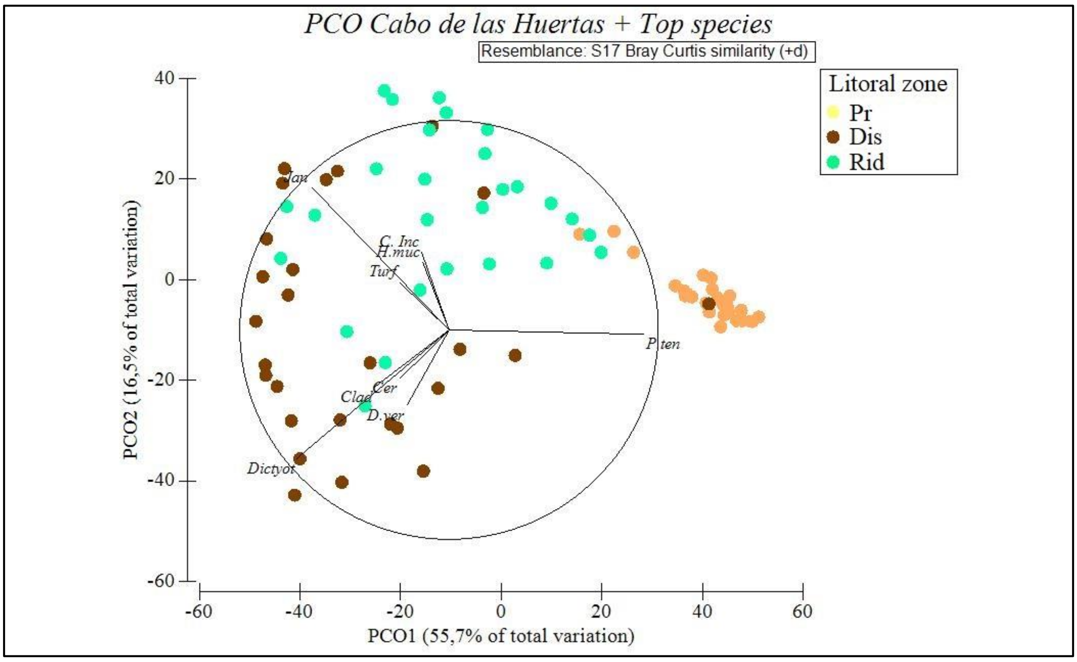
1. Appendix 1 – PCOa

a. Appendix 1.1 PCOa of Cabo de las Huertas

i. Appendix 1.1.1 PCOa with vectors as explanatory variables.

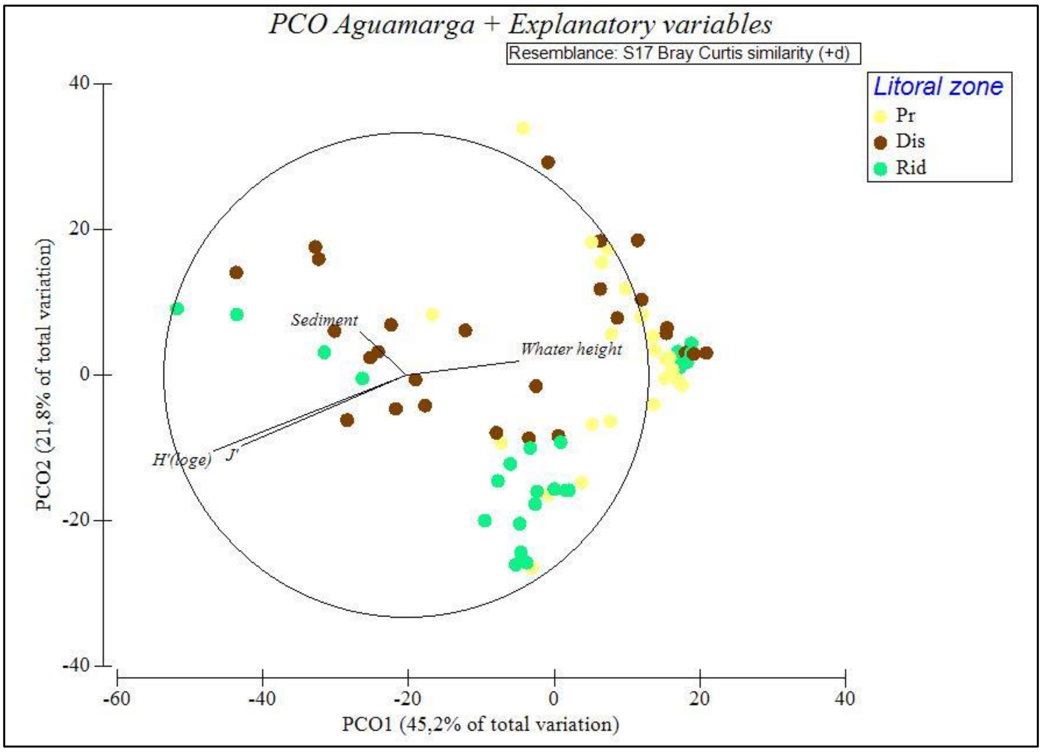


ii. Appendix 1.1.2 PCOa with vectors as most abundant species.

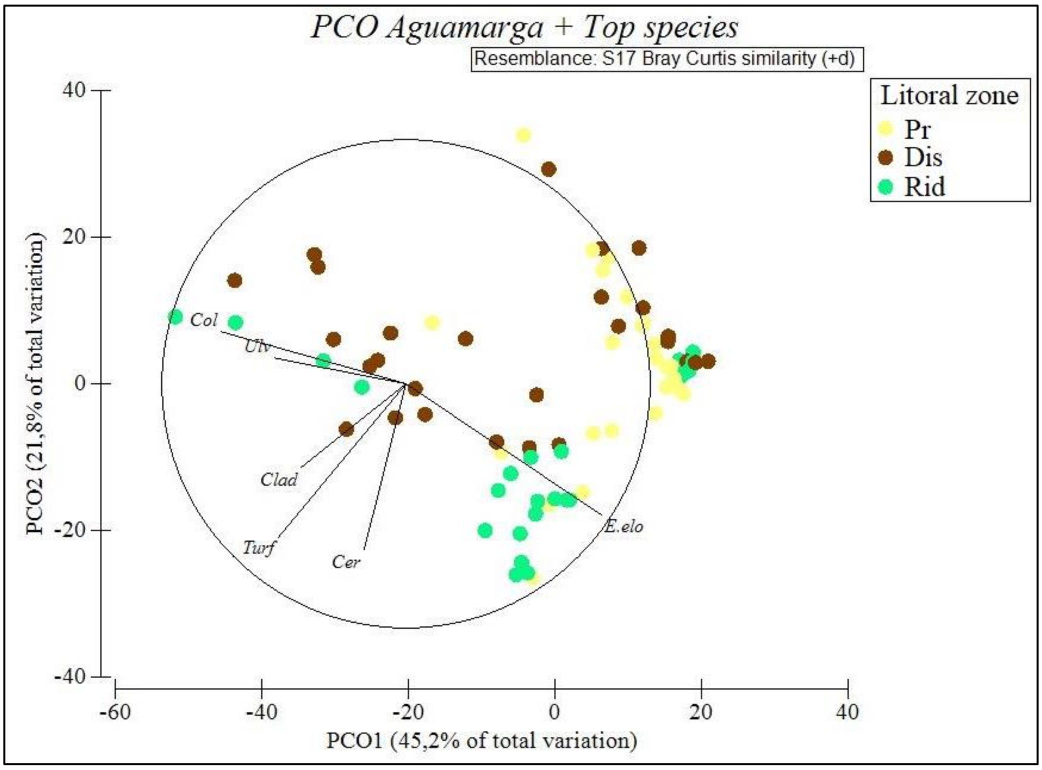


b. **Appendix 1.2 PCOa of Agua Amarga**

i. **Appendix 1.2.1 PCOa with vectors as explanatory variables.**

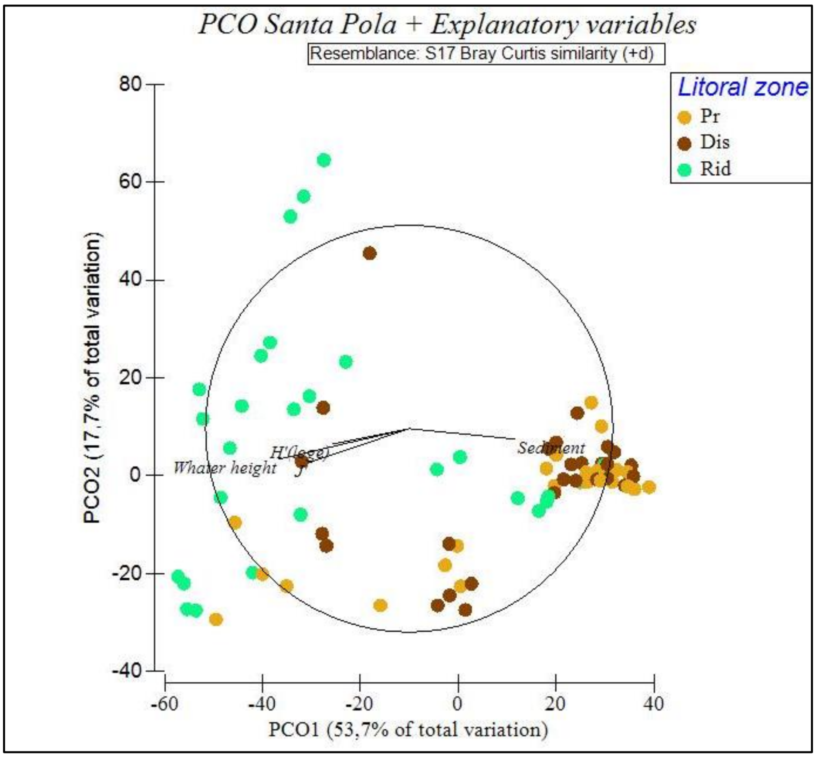


ii. **Appendix 1.2.2 PCOa with vectors as most abundant species.**

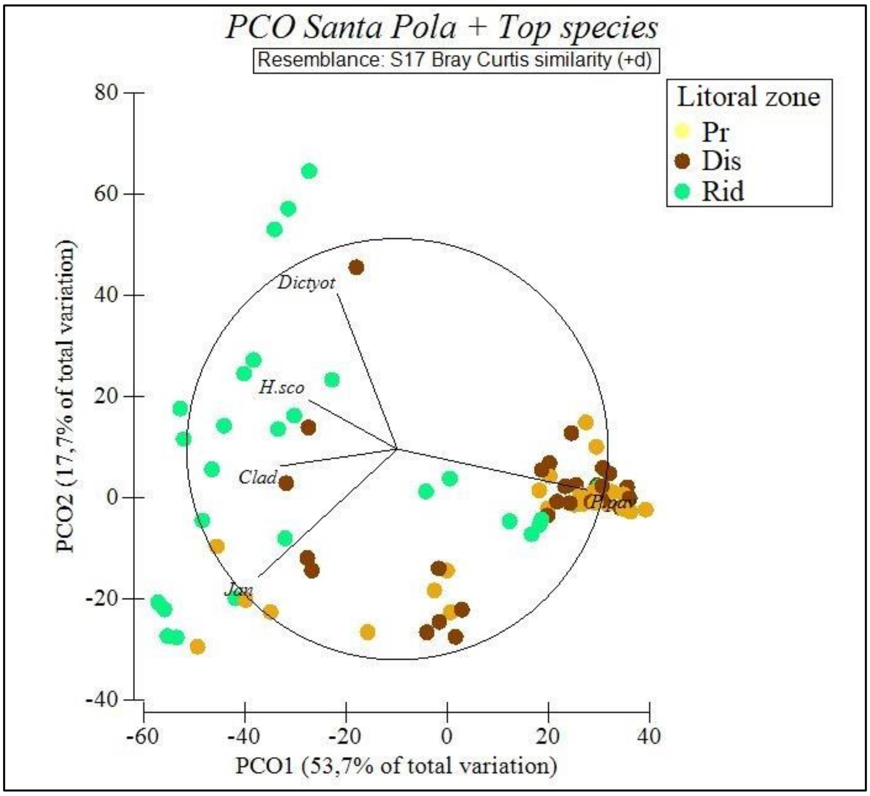


c. **Appendix 1.3 PCOa of Cabo de Santa Pola**

i. **Appendix 1.3.1 PCOa with vectors as explanatory variables.**



ii. **Appendix 1.3.2 PCOa with vectors as most abundant species.**



2. Appendix 2 – PERMANOVA and SIMPER

a. Appendix 2.1 Pair wise PERMANOVA

i. Appendix 2.1.1 P-W test between littoral zones among locations

```
Term 'Loc x Lit.Z' for pairs of levels of factor 'Littoral zone'

Within level 'CH' of factor 'Location'
                              Unique
Groups          t  P(perm)    perms
Pr, Dis    6,0621    0,001       27
Pr, Rid     7,832    0,001       27
Dis, Rid    2,541    0,134       27

Within level 'AA' of factor 'Location'
                              Unique
Groups          t  P(perm)    perms
Pr, Dis     4,363    0,001       27
Pr, Rid    2,2679    0,171       27
Dis, Rid   1,7353    0,202       27

Within level 'CSP' of factor 'Location'
                              Unique
Groups          t  P(perm)    perms
Pr, Dis    2,3768    0,086       27
Pr, Rid     3,439    0,047       27
Dis, Rid   4,0545    0,001       27
```

ii. Appendix 2.1.2 P-W test between months among locations

```
Term 'Loc x Mo' for pairs of levels of factor 'Month'


Within level 'CH' of factor 'Location'
                              Unique
Groups          t  P(perm)    perms
Dec, Feb   3,3382    0,057       27
Dec, Mar   2,9985    0,101       27
Feb, Mar   1,5844    0,232       27

Within level 'AA' of factor 'Location'
                              Unique
Groups          t  P(perm)    perms
Dec, Feb   5,0215    0,001       27
Dec, Mar   4,7917    0,001       27
Feb, Mar   2,8561    0,139       27


Within level 'CSP' of factor 'Location'
                              Unique
Groups          t  P(perm)    perms
Dec, Feb   4,0679    0,039       27
Dec, Mar   3,0251     0,12       27
Feb, Mar   1,1796     0,29       27
```

b. **Appendix 2.2 SIMPER analysis**

i. **Appendix 2.2.1 SIMPER per littoral zones and months of CH**

Examines Littoral zone groups
(across all Month groups)

Group Pr
Average similarity: 75,32

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
P.ten	59,67	67,90	4,97	90,15	90,15
Jan	6,07	4,40	0,71	5,84	95,99
C. Inc	3,30	2,32	0,51	3,08	99,07
P.pav	1,04	0,26	0,24	0,35	99,42

Group Dis
Average similarity: 58,94

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Dictyot	42,37	27,14	1,64	46,04	46,04
Jan	33,04	23,85	1,22	40,46	86,51
P.ten	9,85	3,19	0,48	5,42	91,93
Clad	5,37	1,84	0,44	3,12	95,04

Group Rid
Average similarity: 56,65

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Jan	38,52	26,94	2,19	47,55	47,55
P.ten	20,41	10,91	1,09	19,25	66,80
C. Inc	19,37	8,93	0,99	15,75	82,56
Dictyot	10,11	3,50	0,52	6,18	88,74

Groups Pr & Dis
Average dissimilarity = 78,50

	Group Pr	Group Dis				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
P.ten	59,67	9,85	27,90	2,73	35,55	35,55
Dictyot	0,04	42,37	23,54	1,92	29,99	65,54
Jan	6,07	33,04	15,31	1,34	19,51	85,05
Clad	0,33	5,37	2,98	0,66	3,80	88,84

Groups Pr & Rid
Average dissimilarity = 68,38

	Group Pr	Group Rid				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
P.ten	59,67	20,41	21,79	1,96	31,87	31,87
Jan	6,07	38,52	17,21	1,95	25,17	57,04
C. Inc	3,30	19,37	8,46	1,04	12,36	69,40
Dictyot	0,04	10,11	5,63	0,82	8,24	77,64

Groups Dis & Rid
Average dissimilarity = 55,35

Species	Group Dis Av.Abund	Group Rid Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Dictyot	42,37	10,11	16,55	1,64	29,89	29,89
P.ten	9,85	20,41	8,21	1,28	14,83	44,73
Jan	33,04	38,52	7,59	1,35	13,71	58,44
C. Inc	4,44	19,37	7,35	1,01	13,28	71,71

Examines Month groups
(across all Littoral zone groups)

Group Dec
Average similarity: 68,73

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Jan	43,22	31,41	1,72	45,70	45,70
P.ten	27,78	23,37	0,80	34,00	79,71
Dictyot	14,78	7,60	0,68	11,06	90,77
C. Inc	11,52	3,97	0,44	5,77	96,54

Group Feb
Average similarity: 69,46

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
P.ten	34,37	33,73	0,98	48,56	48,56
Jan	21,89	16,72	1,27	24,07	72,62
Dictyot	16,85	12,21	0,70	17,58	90,20
C. Inc	5,63	3,19	0,86	4,59	94,79

Group Mar
Average similarity: 52,71

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
P.ten	27,78	24,90	0,91	47,24	47,24
Dictyot	20,89	10,82	0,61	20,54	67,77
Jan	12,52	7,05	0,89	13,38	81,15
C. Inc	9,96	5,71	0,83	10,82	91,98

Groups Dec & Feb
Average dissimilarity = 40,02

Species	Group Dec Av.Abund	Group Feb Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Jan	43,22	21,89	11,05	1,33	27,61	27,61
P.ten	27,78	34,37	8,98	1,18	22,45	50,06
Dictyot	14,78	16,85	5,53	0,79	13,82	63,88
C. Inc	11,52	5,63	5,34	0,83	13,35	77,23

Groups Dec & Mar
Average dissimilarity = 50,83

Species	Group Dec Av.Abund	Group Mar Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Jan	43,22	12,52	15,31	1,48	30,12	30,12
P.ten	27,78	27,78	9,88	1,08	19,44	49,56
Dictyot	14,78	20,89	7,23	0,80	14,22	63,78
C. Inc	11,52	9,96	6,63	1,09	13,05	76,84

Groups Feb & Mar
Average dissimilarity = 43,05

Species	Group Feb Av.Abund	Group Mar Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
P.ten	34,37	27,78	10,88	1,24	25,28	25,28
Jan	21,89	12,52	7,33	1,14	17,03	42,30
Dictyot	16,85	20,89	6,87	0,82	15,96	58,26
C. Inc	5,63	9,96	4,63	1,33	10,76	69,01

ii. Appendix 2.2.2 SIMPER per littoral zones and months of AA

Examines Littoral zone groups
(across all Month groups)

Group Pr
Average similarity: 82,45

Species	Av.Abund	Av.Sim	Sim/SD	Contrib %	Cum. %
E.elo	82,07	77,65	5,63	94,17	94,17
Jan	1,93	1,36	0,61	1,65	95,83
Turf	3,48	1,11	0,39	1,34	97,17
Clad	3,96	0,72	0,46	0,88	98,05

Group Dis
Average similarity: 75,36

Species	Av.Abund	Av.Sim	Sim/SD	Contrib %	Cum. %
E.elo	67,70	50,32	3,47	66,76	66,76
Jan	15,93	8,13	1,01	10,79	77,55
Turf	10,81	5,90	1,01	7,82	85,38
Col	5,96	3,49	0,67	4,63	90,01

Group Rid
Average similarity: 80,74

Species	Av.Abund	Av.Sim	Sim/SD	Contrib %	Cum. %
E.elo	84,48	57,03	2,85	70,64	70,64
Turf	21,44	11,25	1,14	13,93	84,57
Jan	8,44	4,29	0,75	5,32	89,88
Clad	5,37	2,20	0,75	2,73	92,61

Groups Pr & Dis

Average dissimilarity = 32,27

Species	Group Pr Av.Abund	Group Dis Av.Abund	Av.Diss	Diss/SD	Contrib %	Cum. %
E.elo	82,07	67,70	9,20	1,43	28,50	28,50
Jan	1,93	15,93	6,42	1,18	19,88	48,38
Turf	3,48	10,81	4,88	1,00	15,13	63,51
Clad	3,96	7,00	3,34	0,60	10,34	73,85

Groups Pr & Rid

Average dissimilarity = 28,05

Species	Group Pr Av.Abund	Group Rid Av.Abund	Av.Diss	Diss/SD	Contrib %	Cum. %
Turf	3,48	21,44	7,81	0,94	27,83	27,83
E.elo	82,07	84,48	6,56	1,01	23,39	51,22
Jan	1,93	8,44	3,03	0,88	10,80	62,02
Col	0,22	6,56	2,97	0,39	10,58	72,60
Clad	3,96	5,37	2,10	0,64	7,49	80,08

Groups Dis & Rid

Average dissimilarity = 29,23

Species	Group Dis Av.Abund	Group Rid Av.Abund	Av.Diss	Diss/SD	Contrib %	Cum. %
E.elo	67,70	84,48	8,26	1,63	28,24	28,24
Turf	10,81	21,44	4,74	1,02	16,22	44,47
Jan	15,93	8,44	4,02	1,05	13,76	58,23
Col	5,96	6,56	3,20	0,66	10,94	69,17

Examines Month groups
(across all Litoral zone groups)

Group Dec

Average similarity: 89,45

Species	Av.Abund	Av.Sim	Sim/SD	Contrib %	Cum. %
E.elo	87,19	77,56	7,47	86,71	86,71
Jan	16,67	10,89	1,56	12,17	98,89
Cha	0,78	0,40	0,81	0,44	99,33
Turf	0,78	0,31	0,34	0,35	99,68

Group Feb

Average similarity: 77,09

Species	Av.Abund	Av.Sim	Sim/SD	Contrib %	Cum. %
E.elo	82,78	56,71	4,22	73,57	73,57
Turf	14,96	6,71	1,26	8,70	82,27
Cer	7,48	3,36	1,26	4,35	86,62
Clad	7,48	3,36	1,26	4,35	90,98

Group Mar
Average similarity: 72,02

Species	Av.Abund	Av.Sim	Sim/SD	Contrib %	Cum. %
E.elo	64,30	50,72	2,22	70,43	70,43
Turf	20,00	11,23	1,12	15,60	86,02
Col	11,41	4,42	0,64	6,14	92,16
Clad	8,85	2,73	0,67	3,79	95,95

Groups Dec & Feb
Average dissimilarity = 29,65

	Group Dec	Group Feb				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib %	Cum.%
Turf	0,78	14,96	5,58	1,62	18,81	18,81
E.elo	87,19	82,78	5,41	1,09	18,26	37,07
Jan	16,67	6,44	5,04	1,27	17,00	54,07
Cer	0,00	7,48	2,87	1,64	9,69	63,76

Groups Dec & Mar
Average dissimilarity = 37,35

	Group Dec	Group Mar				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib %	Cum. %
E.elo	87,19	64,30	11,36	1,25	30,41	30,41
Turf	0,78	20,00	7,51	1,05	20,10	50,51
Jan	16,67	3,19	5,86	1,41	15,68	66,19
Col	0,00	11,41	4,67	0,71	12,49	78,68

Groups Feb & Mar
Average dissimilarity = 35,32

	Group Feb	Group Mar				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib %	Cum. %
E.elo	82,78	64,30	9,34	1,12	26,46	26,46
Turf	14,96	20,00	5,10	1,20	14,45	40,91
Col	1,33	11,41	4,05	0,73	11,46	52,37
Clad	7,48	8,85	3,85	0,87	10,91	63,28

iii. Appendix 2.2.3 SIMPER per littoral zones and months of CSP

Examines Litoral zone groups
(across all Month groups)

Group Pr
Average similarity: 71,31

Species	Av.Abund	Av.Sim	Sim/SD	Contrib %	Cum. %
P.pav	51,56	52,35	1,80	73,41	73,41
Jan	20,07	15,95	0,73	22,37	95,78
C.rac	2,52	1,02	0,67	1,43	97,21
Dictyot	2,67	0,89	0,63	1,25	98,46

Group Dis
Average similarity: 74,15

Species	Av.Abund	Av.Sim	Sim/SD	Contrib %	Cum. %
P.pav	70,56	52,89	1,77	71,34	71,34
Jan	26,93	16,10	0,96	21,72	93,05
Dictyot	9,59	2,92	0,65	3,94	97,00
D.ver	2,89	1,35	0,60	1,81	98,81

Group Rid
Average similarity: 44,95

Species	Av.Abund	Av.Sim	Sim/SD	Contrib %	Cum. %
Jan	32,78	19,63	1,18	43,67	43,67
P.pav	25,04	10,29	0,52	22,88	66,55
H.sco	20,78	6,83	0,47	15,20	81,75
Dictyot	16,44	3,28	0,27	7,30	89,05

Groups Pr & Dis
Average dissimilarity = 33,82

	Group Pr	Group Dis				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib %	Cum. %
P.pav	51,56	70,56	16,62	1,29	49,13	49,13
Jan	20,07	26,93	6,03	0,88	17,84	66,97
Dictyot	2,67	9,59	4,45	0,58	13,16	80,13
D.ver	0,93	2,89	1,49	0,83	4,41	84,54

Groups Pr & Rid
Average dissimilarity = 61,10

	Group Pr	Group Rid				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib %	Cum. %
P.pav	51,56	25,04	19,45	1,60	31,82	31,82
Jan	20,07	32,78	11,45	1,30	18,74	50,57
H.sco	0,44	20,78	10,89	0,74	17,83	68,40
Dictyot	2,67	16,44	8,89	0,60	14,55	82,94

Groups Dis & Rid
Average dissimilarity = 56,48

	Group Dis	Group Rid				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib %	Cum. %
P.pav	70,56	25,04	21,27	1,48	37,66	37,66
H.sco	0,96	20,78	9,64	0,72	17,07	54,73
Jan	26,93	32,78	8,56	1,18	15,16	69,89
Dictyot	9,59	16,44	8,51	0,73	15,07	84,96

Examines Month groups
(across all Littoral zone groups)

Group Dec

Average similarity: 56,34

Species	Av.Abund	Av.Sim	Sim/SD	Contrib %	Cum. %
Jan	55,41	35,35	1,65	62,74	62,74
P.pav	28,07	12,98	0,84	23,04	85,78
Dictyot	17,22	3,87	0,32	6,86	92,64
Clad	4,63	1,57	0,44	2,79	95,43

Group Feb

Average similarity: 70,04

Species	Av.Abund	Av.Sim	Sim/SD	Contrib %	Cum. %
P.pav	66,04	57,82	2,02	82,56	82,56
Jan	12,11	6,68	0,88	9,53	92,09
H.sco	7,81	2,01	0,36	2,86	94,95
Dictyot	5,26	1,89	0,76	2,70	97,65

Group Mar

Average similarity: 64,03

Species	Av.Abund	Av.Sim	Sim/SD	Contrib %	Cum. %
P.pav	53,04	44,73	1,29	69,85	69,85
Jan	12,26	9,66	1,86	15,09	84,94
H.sco	12,19	4,84	0,35	7,56	92,50
D.ver	2,86	1,52	0,66	2,37	94,87

Groups Dec & Feb

Average dissimilarity = 61,43

	Group Dec	Group Feb				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib %	Cum. %
Jan	55,41	12,11	22,58	1,87	36,75	36,75
P.pav	28,07	66,04	20,34	1,38	33,11	69,86
Dictyot	17,22	5,26	7,97	0,66	12,98	82,84
H.sco	2,19	7,81	3,51	0,47	5,72	88,56

Groups Dec & Mar

Average dissimilarity = 60,35

	Group Dec	Group Mar				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib %	Cum. %
Jan	55,41	12,26	21,88	2,13	36,26	36,26
P.pav	28,07	53,04	16,01	1,07	26,53	62,79
Dictyot	17,22	6,22	8,75	0,67	14,50	77,29
H.sco	2,19	12,19	5,45	0,52	9,03	86,32

Groups Feb & Mar
Average dissimilarity = 34,89

	Group Feb	Group Mar				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib %	Cum. %
P.pav	66,04	53,04	13,77	0,88	39,46	39,46
H.sco	7,81	12,19	5,78	0,58	16,55	56,01
Jan	12,11	12,26	4,02	1,27	11,53	67,54
Dictyot	5,26	6,22	3,89	0,58	11,14	78,68

3. Appendix 3 – ANOVA

a. Appendix 3.1 Shannon diversity

i. Appendix 3.1.1 SNK between Locations

```
Level: Proximal.December
                AguaAmarga Huertas SantaPola
Rank order:     1          2       3
Ranked means: 18.7778      53.6667 94.6667
Comparisons:
1               3-1 ***
2               2-1 *      3-2 **

Level: Distal.December
                AguaAmarga Huertas SantaPola
Rank order:     1          2       3
Ranked means: 89.1111      97.2222 130.7778
Comparisons:
1               3-1 *
2               2-1 ns     3-2 *

Level: Ridge.December
                AguaAmarga SantaPola Huertas
Rank order:     1          2         3
Ranked means: 42.4444      105.8889  177.6667
Comparisons:
1               3-1 ***
2               2-1 ***    3-2 ***
```

```
Level: Proximal.February
                Huertas SantaPola AguaAmarga
Rank order:     1       2         3
Ranked means: 34.2222 64.4444     97.5556
Comparisons:
1               3-1 ***
2               2-1 *   3-2 *

Level: Distal.February
                SantaPola AguaAmarga Huertas
Rank order:     1         2          3
Ranked means: 82.1111     170.4444   176.1111
Comparisons:
1               3-1 ***
2               2-1 ***   3-2 ns

Level: Ridge.February
                SantaPola AguaAmarga Huertas
Rank order:     1         2          3
Ranked means: 137.6667    188.2222   204.7778
Comparisons:
1               3-1 ***
2               2-1 ***   3-2 ns
```

```
Level: Proximal.March
                AguaAmarga Huertas SantaPola
Rank order:     1          2       3
Ranked means: 18.6667      78.3333 81.1111
Comparisons:
1               3-1 ***
2               2-1 ***    3-2 ns

Level: Distal.March
                SantaPola Huertas  AguaAmarga
Rank order:     1         2        3
Ranked means: 89          158.8889 197
Comparisons:
1               3-1 ***
2               2-1 ***   3-2 *

Level: Ridge.March
                AguaAmarga SantaPola Huertas
Rank order:     1          2         3
Ranked means: 157          165.5556  224.5556
Comparisons:
1               3-1 ***
2               2-1 ns     3-2 ***
```

ii. Appendix 3.1.2 SNK between Littoral zones

```
Level: Huertas.December
                Proximal Distal  Ridge
Rank order:     1        2       3
Ranked means: 53.6667  97.2222 177.6667
Comparisons:
1               3-1 ***
2               2-1 **   3-2 ***

Level: AguaAmarga.December
                Proximal Ridge   Distal
Rank order:     1        2       3
Ranked means: 18.7778  42.4444 89.1111
Comparisons:
1               3-1 ***
2               2-1 ns   3-2 **

Level: SantaPola.December
                Proximal Ridge    Distal
Rank order:     1        2        3
Ranked means: 94.6667  105.8889 130.7778
Comparisons:
1               3-1 *
2               2-1 ns   3-2 ns
```

```
Level: AguaAmarga.February
                Proximal Distal   Ridge
Rank order:     1        2        3
Ranked means: 97.5556  170.4444 188.2222
Comparisons:
1               3-1 ***
2               2-1 ***  3-2 ns

Level: Huertas.February
                Proximal Distal   Ridge
Rank order:     1        2        3
Ranked means: 34.2222  176.1111 204.7778
Comparisons:
1               3-1 ***
2               2-1 ***  3-2 ns

Level: SantaPola.February
                Proximal Distal  Ridge
Rank order:     1        2       3
Ranked means: 64.4444  82.1111 137.6667
Comparisons:
1               3-1 ***
2               2-1 ns   3-2 ***
```

```
Level: Huertas.March
                Proximal Distal   Ridge
Rank order:     1        2        3
Ranked means: 78.3333  158.8889 224.5556
Comparisons:
1               3-1 ***
2               2-1 ***  3-2 ***

Level: AguaAmarga.March
                Proximal Ridge  Distal
Rank order:     1        2      3
Ranked means: 18.6667  157    197
Comparisons:
1               3-1 ***
2               2-1 ***  3-2 **

Level: SantaPola.March
                Proximal Distal Ridge
Rank order:     1        2      3
Ranked means: 81.1111  89     165.5556
Comparisons:
1               3-1 ***
2               2-1 ns   3-2 ***
```

b. Appendix 3.2 Pielow's evenness

i. Appendix 3.2.1 SNK between Locations

```
Level: Proximal.December
               AguaAmarga Huertas  SantaPola
Rank order:    1          2        3
Ranked means: 21.7778     108.4444 111.1111
Comparisons:
1              3-1 ***
2              2-1 ***    3-2 ns

Level: Distal.December
               AguaAmarga SantaPola Huertas
Rank order:    1          2         3
Ranked means: 76.2222     137.1111  174.7778
Comparisons:
1              3-1 ***
2              2-1 ***    3-2 *

Level: Ridge.December
               AguaAmarga SantaPola Huertas
Rank order:    1          2         3
Ranked means: 72.5556     111.3333  163.4444
Comparisons:
1              3-1 ***
2              2-1 *      3-2 **
```

```
Level: Proximal.February
               Huertas SantaPola AguaAmarga
Rank order:    1       2         3
Ranked means: 37.6667 58.3333   92.7778
Comparisons:
1              3-1 **
2              2-1 ns  3-2 ns

Level: Distal.February
               SantaPola AguaAmarga Huertas
Rank order:    1         2          3
Ranked means: 56.8889   163.2222   206.8889
Comparisons:
1              3-1 ***
2              2-1 ***   3-2 *

Level: Ridge.February
               SantaPola AguaAmarga Huertas
Rank order:    1         2          3
Ranked means: 115.1111  161.7778   176.4444
Comparisons:
1              3-1 **
2              2-1 **    3-2 ns
```

```
Level: Proximal.March
               AguaAmarga SantaPola Huertas
Rank order:    1          2         3
Ranked means: 28.4444     64.3333   92.2222
Comparisons:
1              3-1 **
2              2-1 *      3-2 ns

Level: Distal.March
               SantaPola Huertas  AguaAmarga
Rank order:    1         2        3
Ranked means: 74.8889   164.2222 181.2222
Comparisons:
1              3-1 ***
2              2-1 ***   3-2 ns

Level: Ridge.March
               SantaPola AguaAmarga Huertas
Rank order:    1         2          3
Ranked means: 131.7778  149.4444   207.6667
Comparisons:
1              3-1 ***
```

ii. Appendix 3.2.2 SNK between Littoral zones

```
Level: Huertas.December
               Proximal Ridge    Distal
Rank order:    1        2        3
Ranked means: 108.4444 163.4444 174.7778
Comparisons:
1              3-1 ***
2              2-1 **   3-2 ns

Level: AguaAmarga.December
               Proximal Ridge   Distal
Rank order:    1        2       3
Ranked means: 21.7778  72.5556 76.2222
Comparisons:
1              3-1 **
2              2-1 **   3-2 ns

Level: SantaPola.December
               Proximal Ridge    Distal
Rank order:    1        2        3
Ranked means: 111.1111 111.3333 137.1111
Comparisons:
1              3-1 ns
2              2-1 ns   3-2 ns
```

```
Level: AguaAmarga.February
               Proximal Ridge    Distal
Rank order:    1        2        3
Ranked means: 92.7778  161.7778 163.2222
Comparisons:
1              3-1 ***
2              2-1 ***  3-2 ns

Level: Huertas.February
               Proximal Ridge    Distal
Rank order:    1        2        3
Ranked means: 37.6667  176.4444 206.8889
Comparisons:
1              3-1 ***
2              2-1 ***  3-2 ns

Level: SantaPola.February
               Distal  Proximal Ridge
Rank order:    1       2        3
Ranked means: 56.8889 58.3333  115.1111
Comparisons:
1              3-1 **
2              2-1 ns  3-2 **
```

```
Level: Huertas.March
               Proximal Distal   Ridge
Rank order:    1        2        3
Ranked means: 92.2222  164.2222 207.6667
Comparisons:
1              3-1 ***
2              2-1 ***  3-2 *

Level: AguaAmarga.March
               Proximal Ridge    Distal
Rank order:    1        2        3
Ranked means: 28.4444  149.4444 181.2222
Comparisons:
1              3-1 ***
2              2-1 ***  3-2 ns

Level: SantaPola.March
               Proximal Distal  Ridge
Rank order:    1        2       3
Ranked means: 64.3333  74.8889 131.7778
Comparisons:
1              3-1 ***
2              2-1 ns   3-2 **
```

4. Appendix 4 – Beta diversity

a. Appendix 4.1 Pair-Wise test between littoral zones in CH

```
DEVIATIONS FROM CENTROID
F: 0,36062  df1: 2  df2: 78
P(perm): 0,716

PAIRWISE COMPARISONS
Groups              t  P(perm)
(Pr,Dis)    0,39714    0,725
(Pr,Rid)    0,78769    0,483
(Dis,Rid)   0,51275    0,644

MEANS AND STANDARD ERRORS
Group  Size  Average     SE
Pr       27   39,502  2,2492
Dis      27   40,562  1,4372
Rid      27   41,602  1,4332
```

b. **Appendix 4.2 Pair-Wise test between littoral zones in AA**

```
DEVIATIONS FROM CENTROID
F: 2,6662  df1: 2  df2: 78
P(perm): 0,076

PAIRWISE COMPARISONS
Groups              t  P(perm)
(Pr,Dis)      1,5109     0,14
(Pr,Rid)     0,68867    0,514
(Dis,Rid)     2,2974   3,3E-2

MEANS AND STANDARD ERRORS
Group  Size  Average      SE
Pr       27   38,644  1,4681
Dis      27   35,497  1,4776
Rid      27   39,984  1,2776
```

c. **Appendix 4.3 Pair-Wise test between littoral zones in CSP**

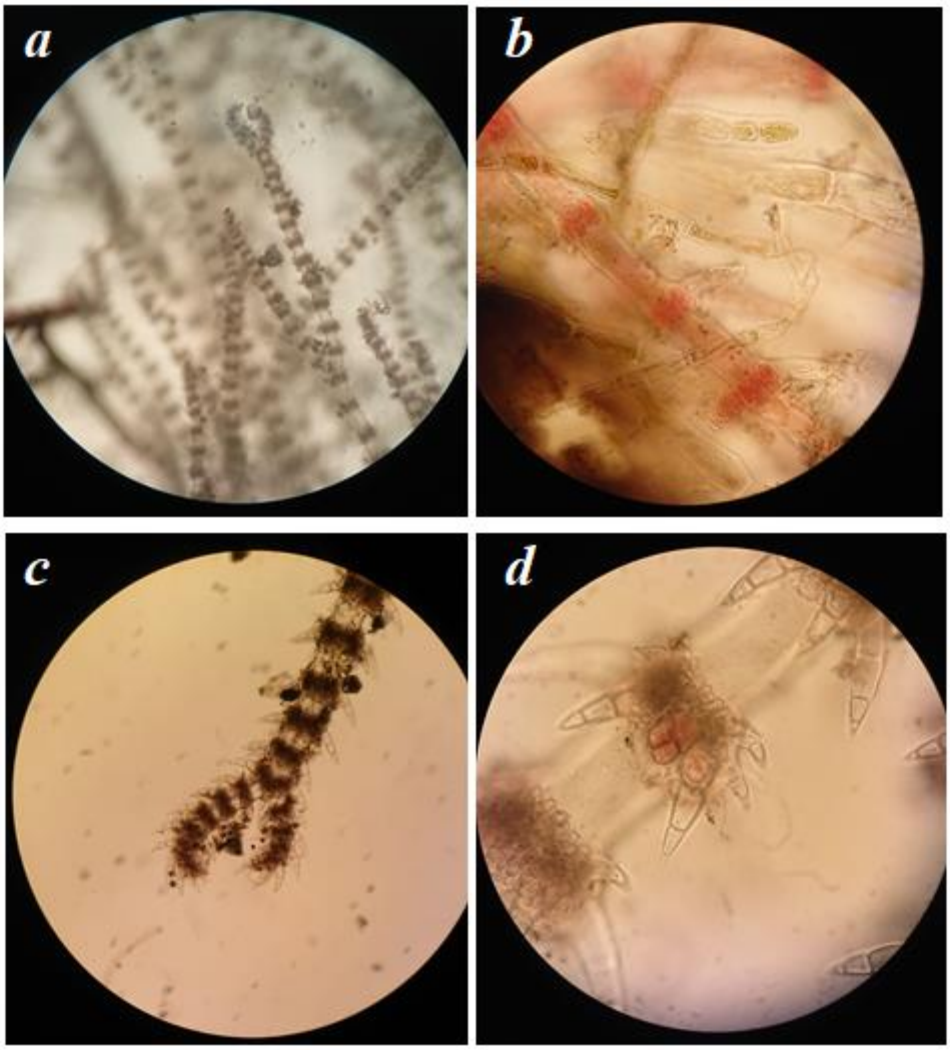
```
DEVIATIONS FROM CENTROID
F: 4,9074  df1: 2  df2: 78
P(perm): 0,013

PAIRWISE COMPARISONS
Groups                t  P(perm)
(Pr,Dis)         2,8767     9E-3
(Pr,Rid)     7,4828E-2     0,949
(Dis,Rid)        2,6004   2,1E-2

MEANS AND STANDARD ERRORS
Group  Size  Average      SE
Pr       27   35,359  1,6175
Dis      27   28,355  1,8195
Rid      27   35,556  2,0875
```

5. **Appendix 5 – EDAR Data:**

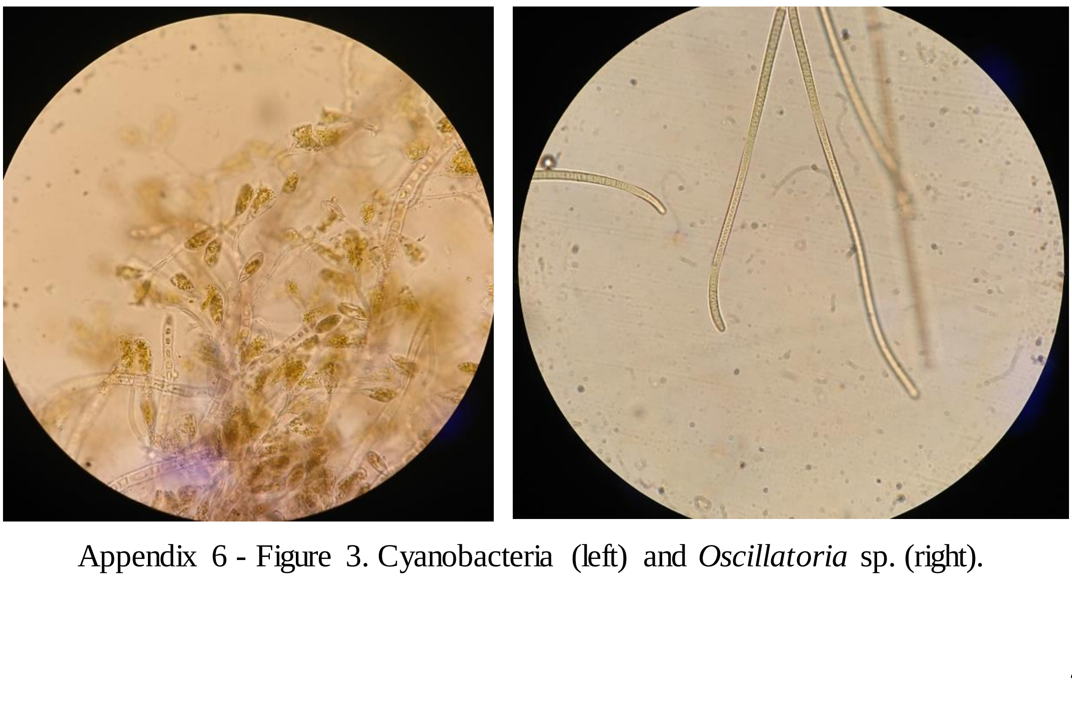
http://www.prtr-es.es/informes/fichacomplejo.aspx?Id_Complejo=6036

6. Appendix 6 – Algae identification: a photographic review.

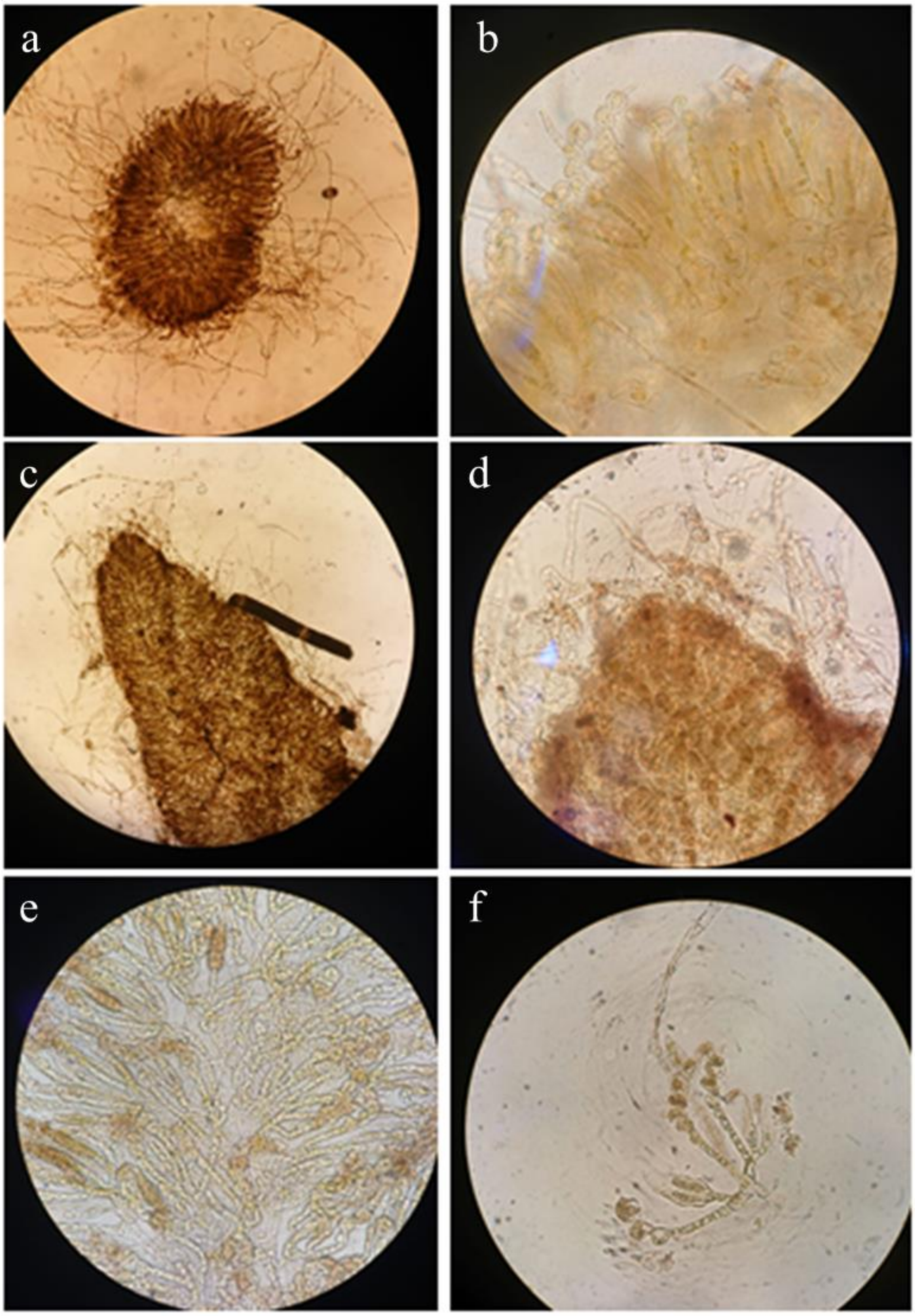
Appendix 6 - Figure 1. Callithamnion granulatum



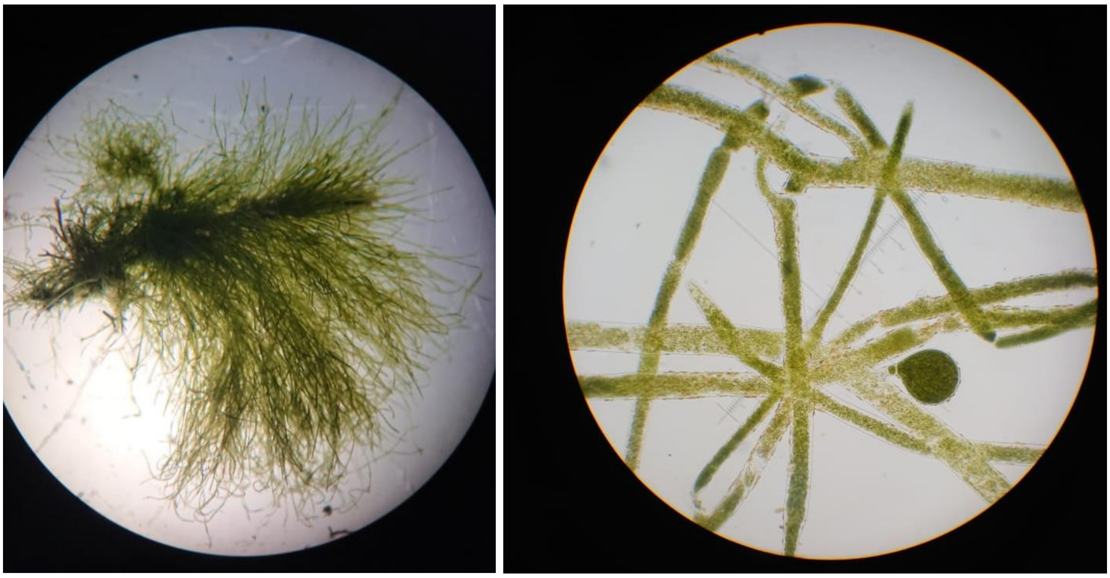
Appendix 6 - Figure 2. *Ceramium Ciliatum* (J. Ellis) (a); Cortication of *C. ciliatum* (b); *C. ciliatum* apex (c); *C.ciliatum* tetrasporangium (d).



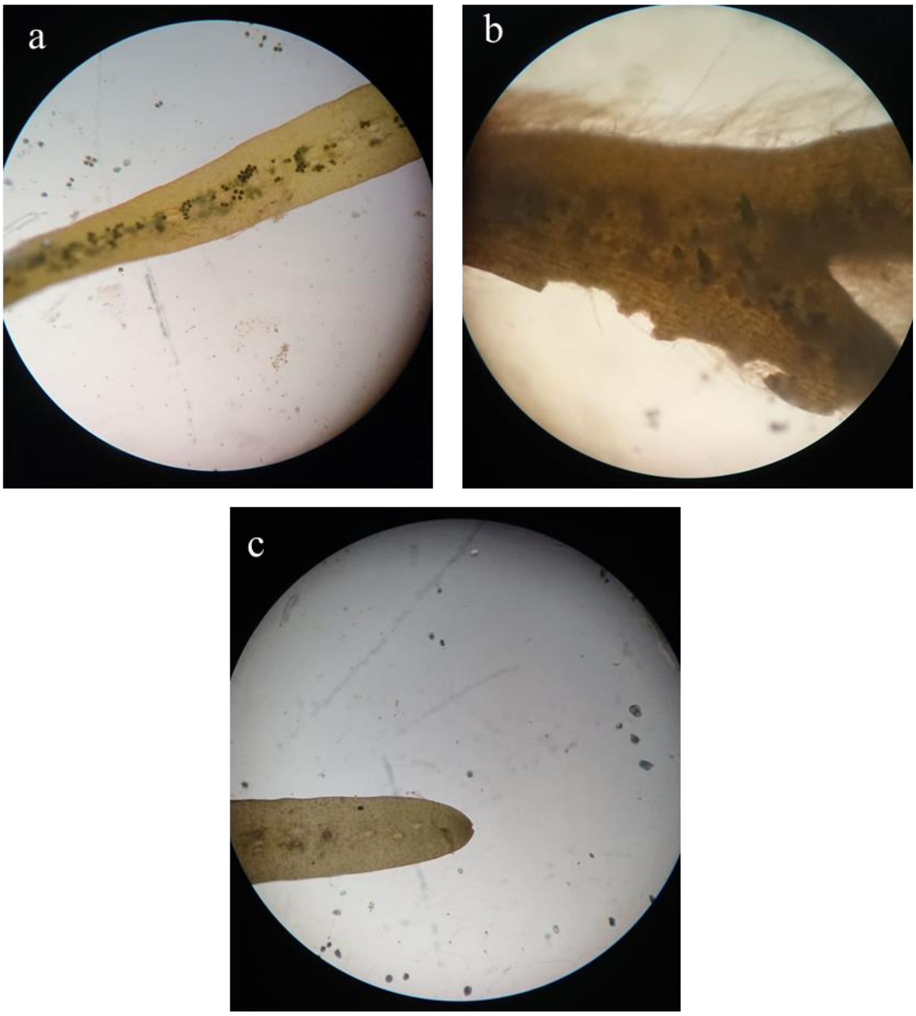
Appendix 6 - Figure 3. Cyanobacteria (left) and *Oscillatoria* sp. (right).



Appendix 6 - Figure 4. Optic cutting of *Cladoscephus spongiosum* (Hudson) (a); cortex of *C. spongiosum* (b); apex of *C. spongiosum* (c and d); medulla of *C. spongiosum* (e); single filament of *C. spongiosum* (f).



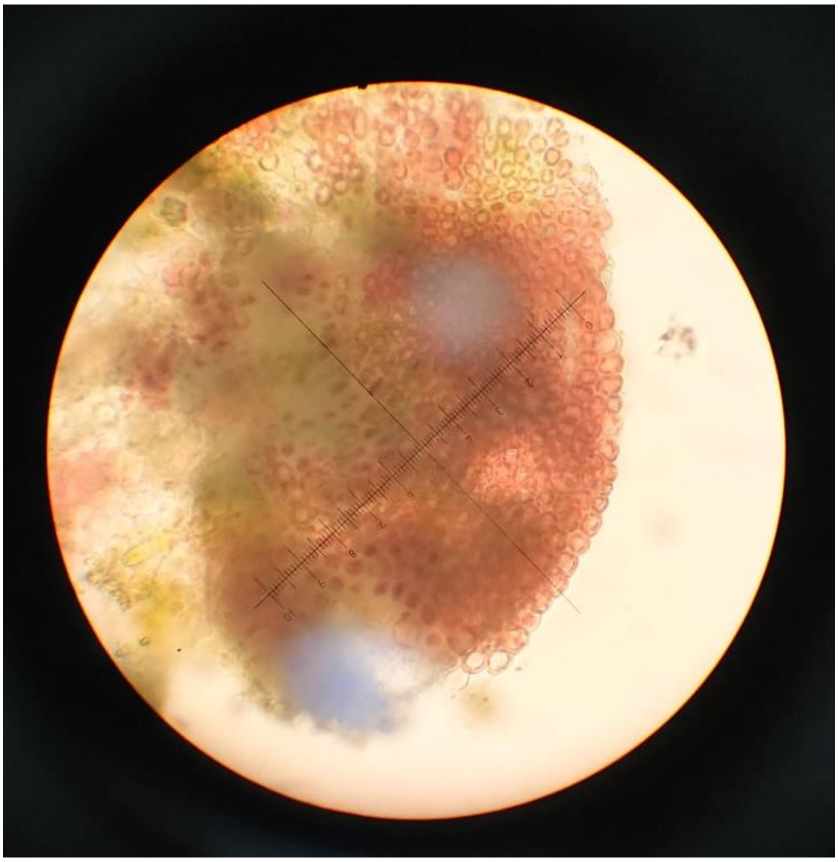
Appendix 6 - Figure 5. *Derbesia tenuissima* (left) with its sporangiums (right)



Appendix 6 - Figure 6. *Dictyota spiralis* (Montagne): (a) fertile specimen with sporangium and (b) phaeophiceae filaments; *D. spiralis* apex.

Appendix 6 - Figure 7. Incipient basal talus of *Ellisolandia elongata*.

Appendix 6 - Figure 8. Segmented axes of *Herposiphonia secunda var. secunda* (Agardh)



Appendix 6 - Figure 9. *Hildembrangia* sp.

Appendix 6 – Figure 10. *Polysiphonia* sp. with a turf of *Ceramium* sp.

7. Appendix 7 – List of algae with full name and abbreviation

FULL NAME	ABREVIATION	FULL NAME	ABREVIATION
Aiptasia sp.	*Aip*	***Dendropoma leb***	*D.leb*
Acetabularia sp.	*Ace*	***Derbesia tenuissima***	*D.ten*
Alsidium corallinum	*A.cor*	***Dictyota* sp.**	*Dictyot*
Amphiroa beauvoisii	*A.bea*	***Dyctiopteris* sp.**	*Dictyop*
Botrilloides leachii	*B.lea*	***Gastroclonium clavatum***	*G.clav*
Callithamnion granulatum	*C.gra*	***Gelidiales***	*Gel*
Caulerpa prolifera	*C.pro*	***Halopteris scoparia***	*H.sco*
Caulerpa cilindracea	*C.cil*	***Herposiphonia secunda var. Secunda***	*H.sec-sec*
***Ceramium* sp.**	*Cer*	***Hildembrangia* sp.**	*Hil*
Chaetomorpha	*Cha*	***Hypnea muciformis***	*H.muc*
Chalinula limbata	*C.lim*	***Jania* sp.**	*Jan*
***Chondria* sp.**	*Cho*	***Mesogloia levelleii***	*M.lev*
***Cladophora* sp.**	*Clad*	***Mytilaster* sp.**	*Myt*
Cladostephus spongiosum	*C.spo*	***Osmundea verlaquei***	*O.ver*
***Colpomenia* sp.**	*Col*	***Padina pavonica***	*P.pav*
***Collumbella* sp.**	*Coll*	***Paguridae***	*Pag(Cru)*
Cor. Incrust	*C. Inc*	***Palissada tenerrima***	*P.ten*
Elysolandia elongata	*E.elo*	***Rivularia* sp.**	*Riv*
Cystoseira compressa	*C.com*	***Scytosiphon lamentaria***	*S.lam*
Cystoseira foeniculacea f. latiramosa	*C.foe-lat*	***Stramonita* sp.**	*Stra*
Cystoseira humilis	*C.hum*	***Turf***	*Turf*
Cystoseira stricta	*C.str*	***Ulva* sp.**	*Ulv*
Dasycladus vermicularis	*D.ver*	***Vermetus* sp.**	*Ver*